Laying Out for Boiler Makers

and

Sheet Metal Workers

A Practical Treatise on the Layout of Boilers, Stacks, Tanks, Pipes, Elbows, and Miscellaneous Sheet Metal Work

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OVER 425 ILLUSTRATIONS

NEW YORK
THE BOILER MAKER
17 Battery Place
1907

Reprinted from

THE
BOILER MAKER

PREFACE

This book has been compiled for the purpose of giving the practical boilermaker the information necessary to enable him to lay out in detail different types of boilers, tanks, stacks and irregular sheet metal work. While the work of laying out, as it is carried on in the boiler shop, requires considerable technical knowledge in addition to that gained by a practical mechanic in the course of his experience in the shop, yet a complete mastery of such subjects as geometry, mechanics and similar branches of elementary mathematics is not essential for doing the work. For this reason no attempt has been made to present these subjects separately from a theoretical standpoint. The practical application of certain of the principles involved in these subjects is, however, very important, and this has been explained in a practical way in connection with different jobs of laying out which form a part of the every-day work in every boiler shop. Only those layouts which are of immediate material use to boilermakers are described, and as far as possible the minor details are given so as to make each problem complete.

The first two chapters explain the methods of laying out by orthographic projection and triangulation, since these are the two principal methods used in solving any problem in laying out. A few simple problems are given in each case from which the application of the methods to more complicated problems may be learned. The chapters which take up the detailed layout of different types of boilers give not only the methods for laying out the actual boiler but also the rules for determining the size, shape and strength of the different parts. These computations are given more in detail in the case of the plain tubular boiler since the problems involved in this case are general and may be applied to almost any other type of boiler.

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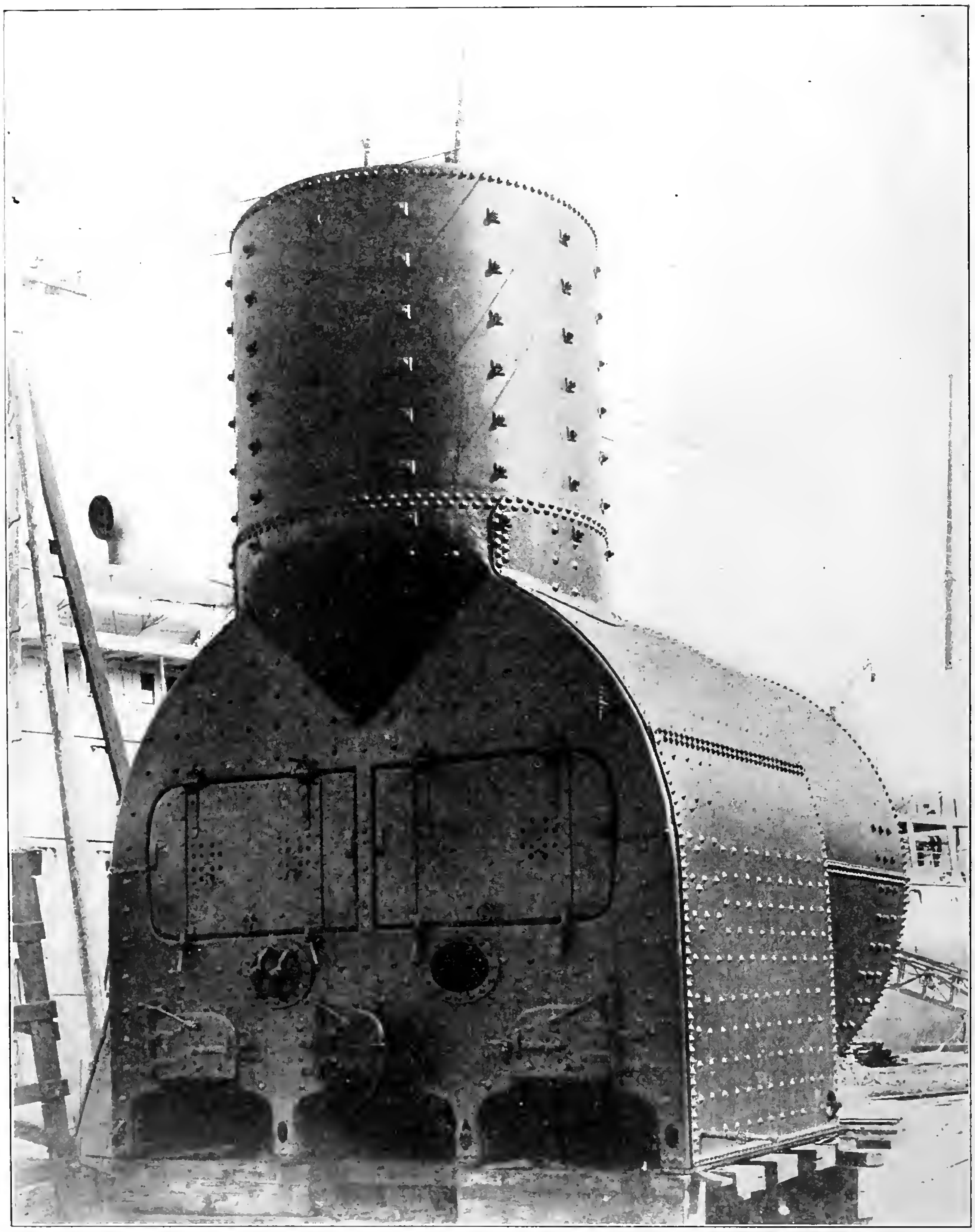


FLUE AND RETURN TUBULAR BOILER INSTALLED ON THE UNITED STATES REVENUE CUTTER "PERRY." 11 FEET 6 INCHES DIAMETER BY 17 FEET LONG, STEAM PRESSURE 60 POUNDS PER SQUARE INCH.

THE SUBJECT OF LAYING OUT

The work of laying out in a boiler shop consists of first determining from blue prints or drawings the true size and shape of the plates, bars, etc., of which an object is to be constructed, and of then marking out on the material itself to these dimensions the lines on which it is to be cut and shaped. This necessitates on the part of the layer out a knowledge of some of the more common problems in plane geometry, such as are ordinarily used in drafting; a knowledge of that part of descriptive geometry which deals with the development of the surfaces of solids of all kinds; and an intimate knowledge of the behavior of the material which is used in the construction, when it is being punched, rolled, flanged, etc.

The work of a layer out is similar in many respects to that of a draftsman, except that it is done to a much larger scale, with coarser instruments, and upon iron and steel instead of paper. While some of it is merely copying what the draftsman has already worked out, yet the layer out must know how to construct accurately the common geometrical figures and figure out their dimensions, as he often has to work out in detail what the draftsman indicates only in a general way. He must know how to find the development of the surfaces of all kinds of solids, because most of the drawings of the various objects made in a boiler shop give only the dimensions of the completed article, showing the plates, angles, etc., after they have been bent or forged to the required shapes. From these dimensions the layer out must find the exact size and shape of every piece of material when laid out flat, so that after it has been cut out and shaped by these lines it will be of exactly the required size and shape and fit accurately in its proper place. To get this result, the layer out must not only understand how to find the development of different surfaces, but he must also know how the material will behave when it is being bent, flanged, forged, etc., for in some instances the metal will be drawn out, or "gain" in length, while in others it will be upset, or "lose" in length. Allowances must be made for these "losses" and "gains" when the plate is laid out, and while, in certain cases, rules can be given for this, the most successful man will have to depend upon his experience for this knowledge. For this reason every layer out should be a practical boiler maker, and have a thorough understanding of the boiler maker's trade, as he will then more readily understand when such allowances should be made and how much they should be.

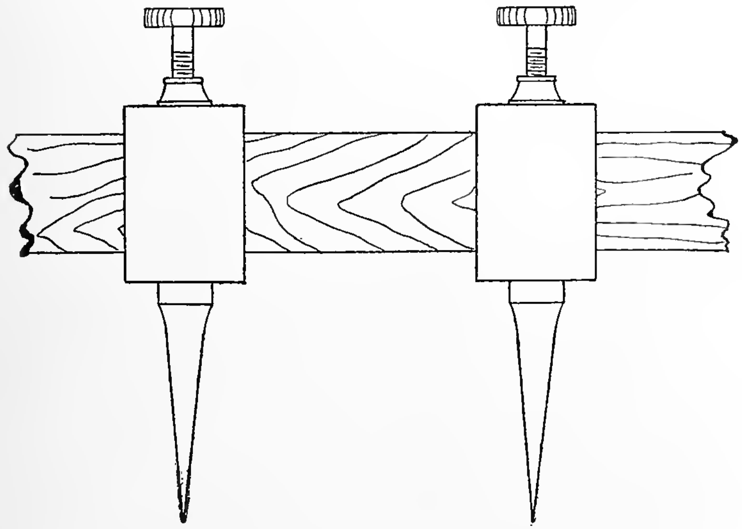


FIG. I.—TRAMMELS.

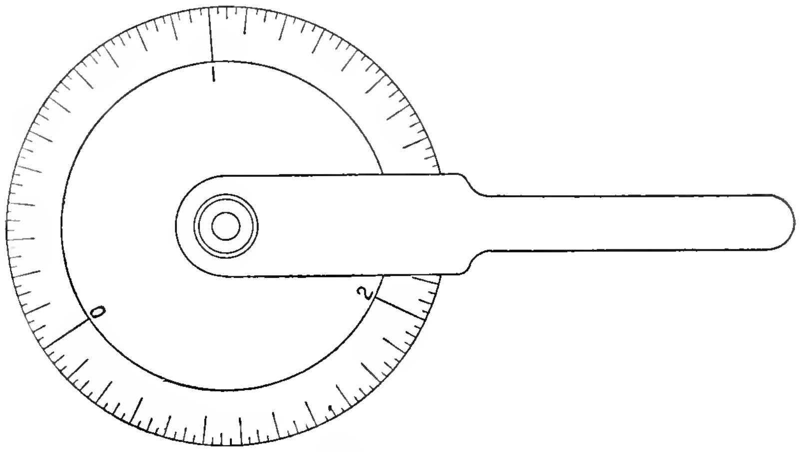


FIG. 2.—MEASURING WHEEL.

Most of the tools and instruments used by a layer out in his work are well known to a boiler maker and need little explanation. The lines are drawn in with chalk or soapstone pencils. Long, straight lines are snapped in with a chalk line. Short ones are drawn in with a steel straight edge. Circles are drawn with trammels, or, as they are more commonly called "trams," a sketch of which is given in Fig. I.

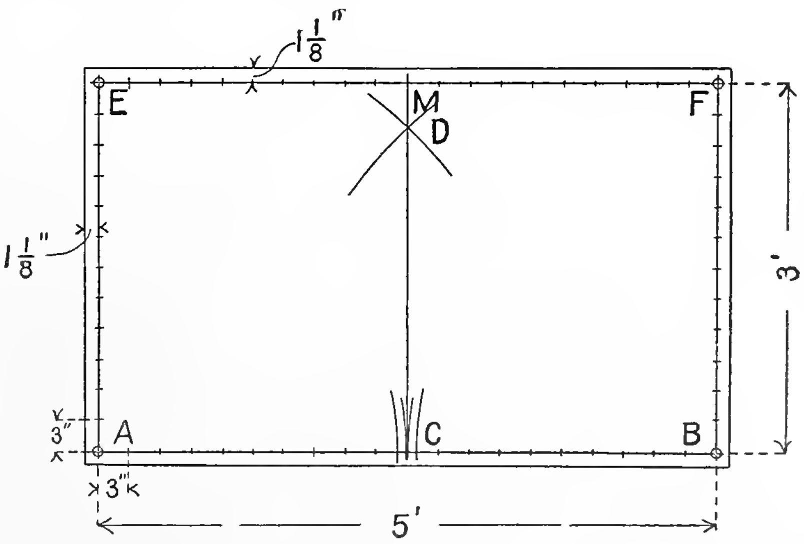


FIG. 3.

This instrument consists of two steel points fastened to metal blocks which slide upon a rod or stick of sufficient thickness to resist bending. The blocks can be clamped at any point on the rod by screws. Circles of small diameter are drawn in with dividers. A more common use of the dividers, however, is that of spacing off a succession of equal distances, as in spacing rivet holes.

Lines are drawn at right angles to each other, or "squared up" by means of a steel square, although this cannot be depended upon where great accuracy is required, as the sides of the square are too short to determine the direction of a long line. The method of "squaring up" lines by a geometrical construction will be explained later. All measurements along straight lines are made with an ordinary 2-foot rule or steel tape. For measuring along curved lines, the tape may be used by holding it to the curve at short intervals, but a better device is the measuring wheel, as shown in the illustration.

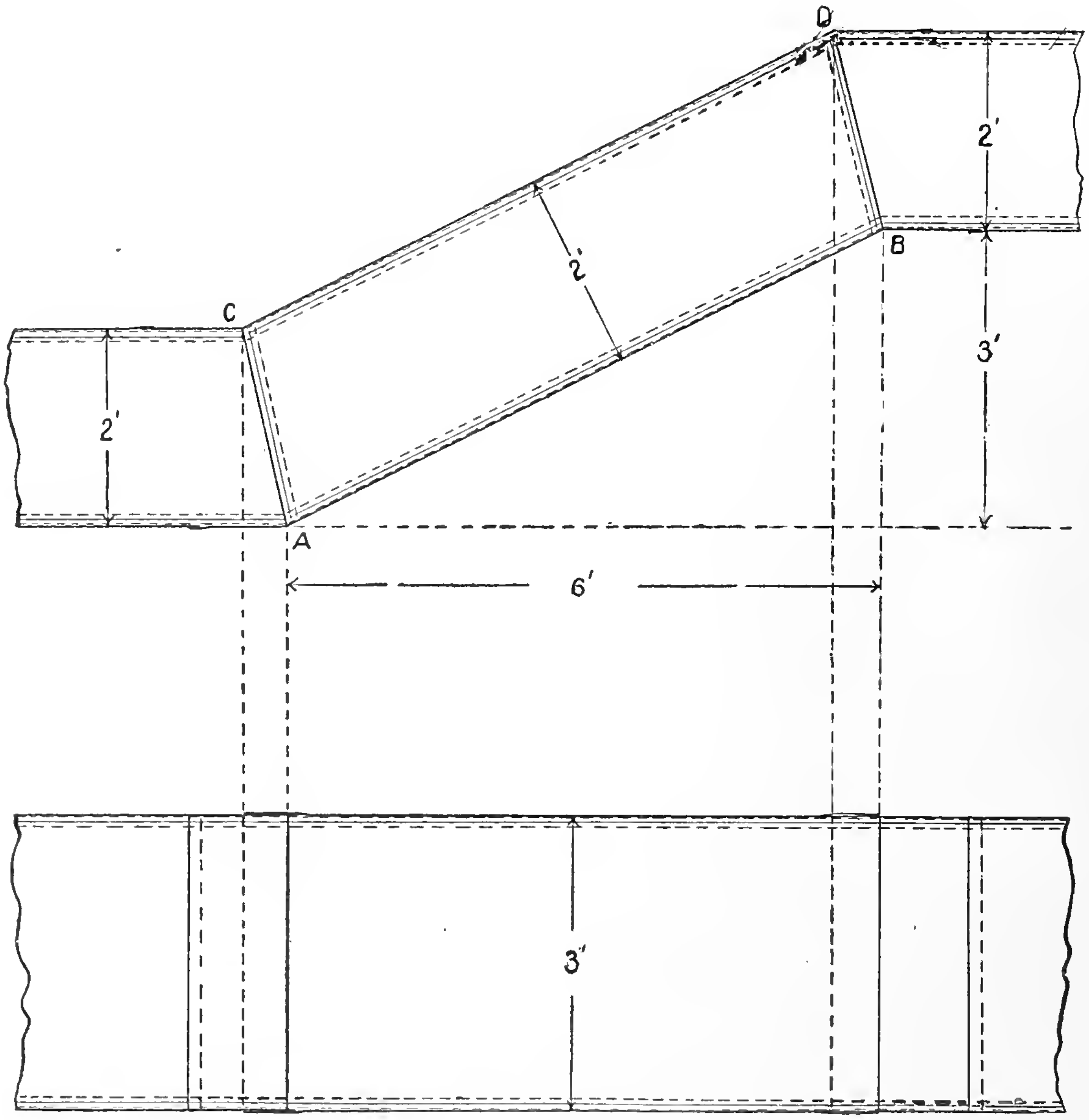


FIG. 4.—PLAN AND ELEVATION.

This wheel is made of a thin piece of metal, beveled to a sharp edge, and having a circumference of a certain exact length, as 2 or 3 feet, with the divisions in inches and fractions of an inch marked upon it. The wheel is pivoted to a handle and can be run over the line, measuring its length exactly. If it is impossible to get one of these graduated wheels, a blank wheel of any diameter may be used by first running it over a straight line on which the distance to be layed off has been marked, and noting the number of complete revolutions of the wheel and placing a mark upon it at the fractional part of a turn left over. Then the wheel can be run over the curved line until it has made the same number of complete revolutions and the end of the curve marked at the point on the wheel indicating the fractional part of a revolution remaining.

The use of these tools, as well as the construction of the ordinary geometrical problems, will be apparent from the problems in laying out which are to be taken up and fully explained. Also such rules as can be given for the allowances to be made due to bending, flanging, etc., will be explained in connection with these layouts.

In general, there are four kinds of surfaces which must be dealt with in boiler work, and of which the layer out must be able to find the development. These are plane surfaces, cylindrical surfaces, conical surfaces and irregular curved surfaces. A plane surface is one in which all the lines lie in the same plane, that is, an ordinary flat surface. A cylindrical surface is one which is formed by a line moving parallel to itself in a curved path. The most common form of the cylinder is that in which this path is a circle. A conical surface is in a similar manner generated by a straight line and has a circular or elliptical cross section; but the surface tapers to a point instead of being formed of parallel lines, as in the cylinder. All surfaces which do not come under the above types may be included in the last division, that of irregular curved surfaces, and must be developed by special methods.

PLANE SURFACES.

Plane surfaces are very simple to lay out, as usually their true dimensions are given on the blue print or drawing, so that it is only a matter of drawing out the outline of the surface to these dimensions. There is always one operation, however, which must be performed upon every plate that is layed out, and that is squaring it up. Squaring up a plate means, practically, drawing upon it two lines at right angles to each other so that all dimensions of length can be laid off along or parallel to one of these lines, and all dimensions of breadth can be laid off along or parallel to the other line.

A plate is squared up as follows: Consider the plate shown in Fig. 3, which is to be laid out rectangular in shape with a length of 5 feet between the center lines of the rivet holes at each end of the plate, and a width of 3 feet between the upper and lower rows of rivets. Assume the lap or distance from center of rivet to edge of plate to be $1\frac{1}{8}$ inches. Then draw a line for the lower row of rivets, as *AB*, $1\frac{1}{8}$ inches from one edge of the plate. Locate the point *A* $1\frac{1}{8}$ inches from one end of the plate and *B* at a distance of 5 feet from *A*. Put in center punch marks at *A* and *B*, and then locate the middle point *C* of the line *AB*. This may be done by measurement, or with the trams as follows: Set the trams by guess at about half the length of *AB*, and with *A* and *B* as centers strike arcs intersecting *AB*. These arcs will probably be only a short distance apart, and of course the center of the line is at the center of the distance between the arcs.

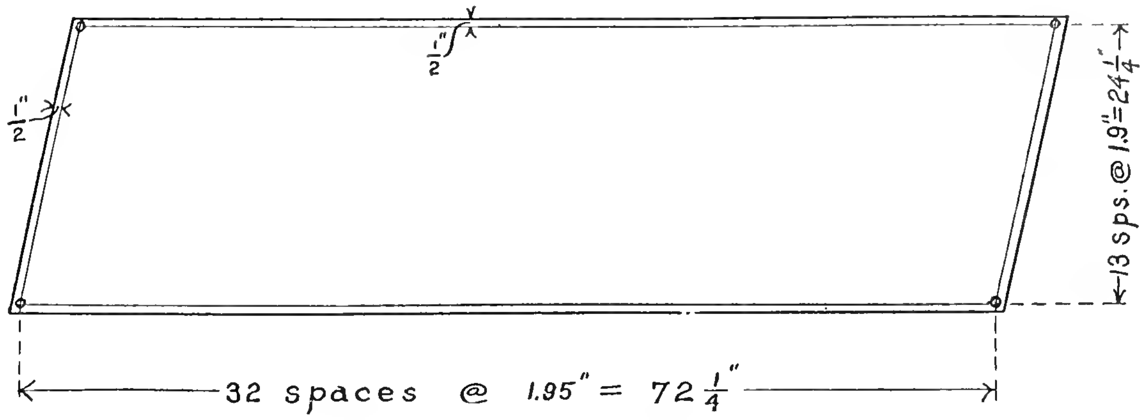


FIG. 5.—TOP PATTERN.

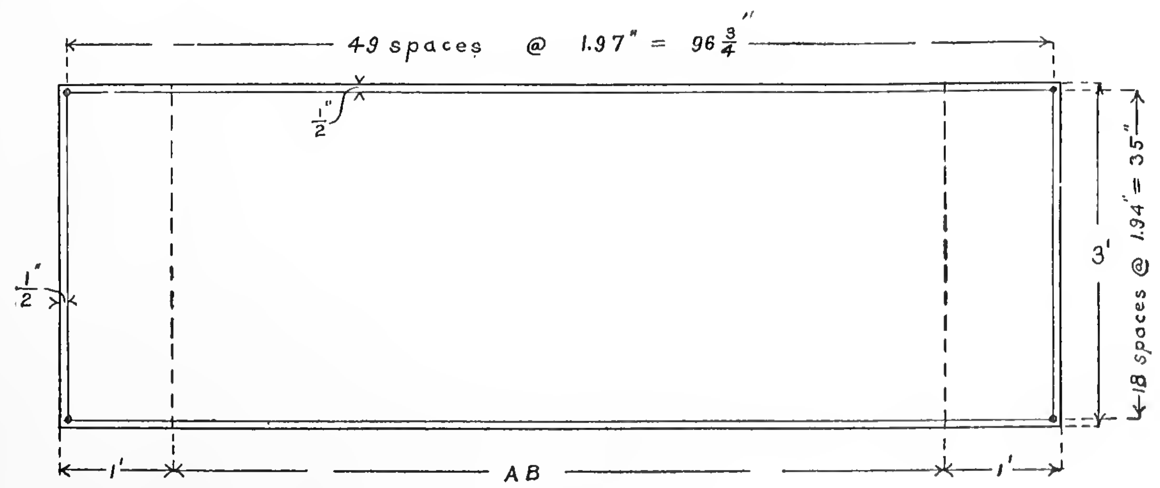


FIG. 6.—SIDE PATTERN.

The trams can now be reset to very nearly one-half *AB*, and arcs struck as before. The arcs will practically intersect the line at the same point this time, and a center punch mark can be put in at exactly the middle point of the line. Now with *A* and *B* as centers and a radius greater than *AC* strike arcs intersecting at some point *D* above the line. Then a line drawn through *C* and *D* will be at right angles to, or "squared up" with, *AB*.

The lines for the other rows of rivets can now be drawn in as follows: Draw *EF* at a distance of 3 feet from *AB*, cutting the center line *CD* at *M*. Then with the trams set to the distance *AC* and with *M* as a center strike arcs cutting *EF* at *E* and *F*. Join *A* and *E*, *B* and *F*, and then you have the center lines of the rows of rivets squared up and drawn in according to the dimensions called for. If the plate has been ordered to size and sheared with the corners square, a $1\frac{1}{8}$-inch lap should remain all around the plate outside the rivet lines. It is never safe to assume that the edges of a plate, as it comes from the mill, have been sheared out square with each other, and so lay out the plate from them. They may be very nearly square, but the rivet lines must be laid out exactly square or the plate will not fit when put in place.

After the plate has been squared up and the rivet lines drawn in, the rivet holes must be spaced in. This is most easily done with the dividers, stepping the spaces off on the lines which have been drawn on the metal; but where the same spacing is to be used again, it may be done on a thin strip of

wood, called a regulator or gage, and then the spaces marked from this upon the metal. In either case, set the dividers roughly to the pitch or distance between the centers of the rivet holes called for by the drawing, and, starting with one point of the dividers at one end of the line, step off the spaces until the other end of the line is reached. If this setting of the dividers leaves a fraction of a space at the end of the line, reset the dividers and go over it again until the last space is exactly equal to the others. Mark these points with a deep center punch mark, to aid in centering the punch or drill when the holes are put in the plate.

The plate should now be marked with white paint, showing the number of the job or contract for which it is to be used, the size of the rivet holes, and any other information necessary to tell what operations should be performed upon it in the shop or how it should be assembled in the finished article.

Fig. 4 shows a portion of a rectangular flue leading from the uptakes of a battery of boilers to the stack. This is made up entirely of flat surfaces fastened together with inside angles. As the top and bottom plates are alike, it is necessary to get the layout of only one of the plates, which may then be used as a pattern for the other. Similarly, one pattern will do for the two sides.

First lay out the plan full size according to the dimensions of the drawing. Then the lengths of the plates can be measured directly from this plan. Since the plates are only ⅛ inch thick, no allowance will have to be made for the bends at *A* and *B*. Consider that there will be a joint in the side plates 1 foot from each bend. Then lay out the side pattern as follows: Lay off the width of the plate from edge to edge as 3 feet. Strike in the rivet lines, leaving ½-inch lap. Square up the rivet line at one end of the plate, leaving a ½-inch lap. Then measure 1 foot from the edge of the plate and square up a line on which the plate is to be bent. Then lay off from this the distance *AB*, measuring it from the full-size plan already laid out. Square up another line for the bend at *B*, and measure 1 foot beyond that for the edge of the plate. Strike in the rivet line ½ inch back from this edge. Now space off the rivet holes; ¼-inch rivets will be used, therefore space them about 1½ inches or 1¾ inches between centers.

The plan which has been layed down full size will serve as a pattern for the top and bottom plates. Make the joints at the lines *AC* and *BD*, so that a plate will not have to be cut out with a reëntrant angle, as that would mean a loss of material. Strike in the rivet lines, leaving a ½-inch lap all around the plate, and space in the rivet holes at about 1½ inches or 1¾ inches.

Patterns showing the angles to which the angle bars are to be bent must be made for the blacksmith. Unless the layer out feels sure of the amount to be allowed for the bends in the bars, the rivet holes should not be spaced in until after they are bent. Care should be taken not to bring a joint in the angles at the same place as a joint in the plates.

While this is a very simple layout, and one which is easily understood from the drawing, the apprentice will find little difficulty with any other problem involving only plane or flat surfaces, as the size and shape of the plates can easily be found, and few allowances must be made. As nearly all problems involve cylindrical or other curved surfaces, we will next take up the method of developing such surfaces.

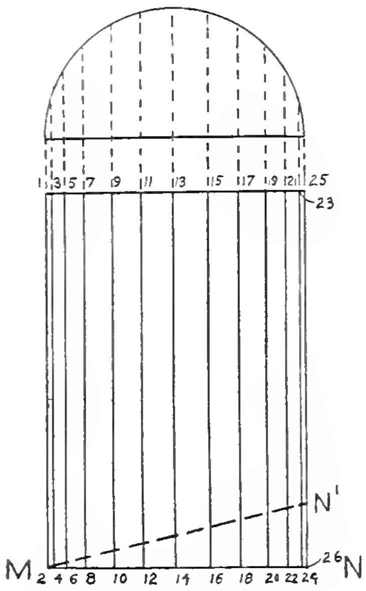


FIG. 7.

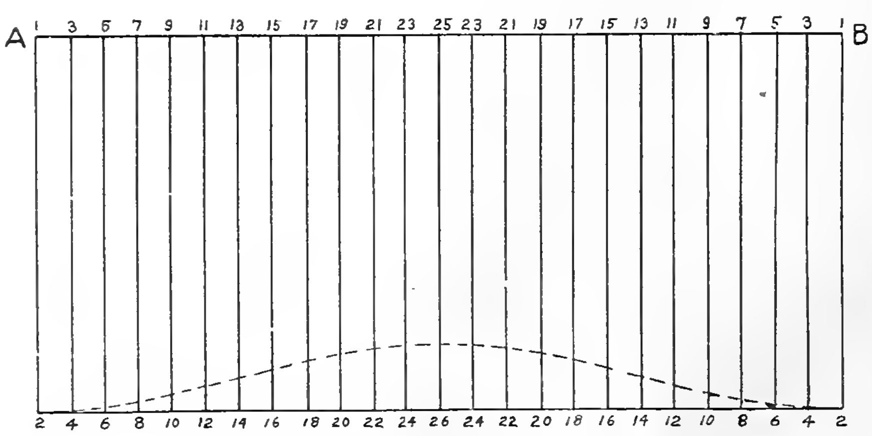


FIG. 8.

CYLINDRICAL SURFACES.

Cylindrical surfaces are laid out by a method of parallel lines; for instance, in developing the surface of the cylinder shown in Fig. 7, proceed as follows: Draw a half view of the plan and divide the semi-circumference into any number of equal parts, in this case twelve. Project lines down from these points of division upon the cylinder. Lay out the line *AB*, Fig. 8, equal to the length of the circumference of the base of the cylinder and divide it into the same number of equal parts into which the base was divided; in this case twenty-four as the semi-circumference was divided into twelve equal parts. Draw lines at right angles to *AB* at these points and lay off along them the lengths of the corresponding lines in Fig. 7. When each base of the cylinder is at right angles with the axis as in Fig. 7, all of these lines are equal so the developed surface will be a rectangle. If the base *MN* had been inclined as *MN'*, then the length of each of the parallel lines would

have been different and it would have been necessary to measure each line separately and lay it out on the corresponding line in the development. Then the bottom edge of the developed surface would have the form shown by the dotted line in Fig 8, the numbers showing the corresponding lines on the cylinder and development.

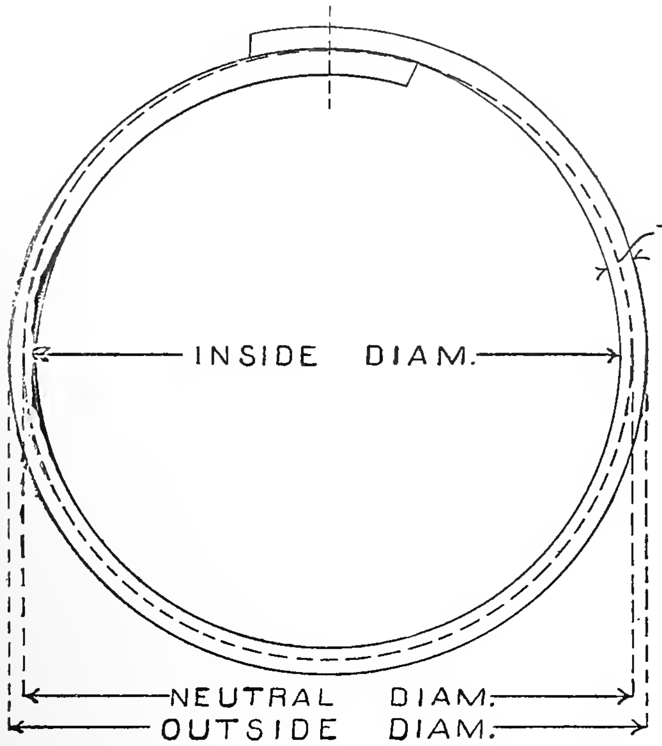


FIG. 9.

Before taking up the actual layout of a cylindrical boiler or tank shell, the apprentice must first be able to find the circumference of a circle in order to get the length of the plate corresponding to the distance *AB* in Fig. 8, as this line was made equal to the length of the circumference of the base of the cylinder. The circumference of a circle is equal to 3.1416 times its diameter. If the apprentice is not familiar with the use of decimals, the same result may be obtained by multiplying the circumference by 22 and dividing by 7. In nearly all engineers' and boiler makers' hand-books, tables are given, in one column of which are values of diameters, and in another column the corresponding values of the circumferences of the circles, and in a third column the values of the areas of the circles. The area of a circle is equal to 3.1416 times its radius squared. The use of such tables will greatly reduce the labor of computation and the chances of making mistakes.

As the material used in boiler construction has considerable thickness, it will be apparent that when a plate is rolled up in the form of a cylinder, the diameter at the inside of the plate is less than the diameter at the outside by twice the thickness of the plate; therefore, the circumference corresponding to the inside diameter will be considerable less than that corresponding to the outside diameter. When laying out the plate it will be seen that neither of these values for the circumference should be used for the length of the plate, as one would be too short and the other too long; but the circumference of a circle, whose diameter may be called the neutral diameter or the diameter to the middle of the thickness of the plate will be the correct one to use. Thus, in Fig. 9, if a half-inch plate is to be rolled to a cylinder whose inside diameter is 48 inches, the plate must be laid out with a length between the center lines of the rivet holes equal to the circumference of a circle whose diameter is 48½ inches, or referring to Fig. 9, it will be seen that if t = the thickness of the material and D the inside diameter, then the neutral diameter is $D + 2 \times \frac{1}{2}$ t or D + t. Therefore the circumference corresponding to this diameter is $3.1416 \times (D + t)$ or $3.1416\ D + 3.1416\ t$. That is, it is equal to the circumference corresponding to the inside diameter plus 3.1416 times the thickness of the plate. For ordinary work three times the thickness of the plate is generally used. The circumference corresponding to the outside diameter might have been found, in which case three times the thickness of the plate should have been subtracted from it. When two rings or courses of plates are to be joined together, one of which is an inside and the other an outside ring, the circumference corresponding to the neutral diameter of the inside ring may be found, and then for the length of the outside plate six times the thickness of the material should be added to this. This will make a close fit between the rings, as the exact amount to be added is 2 times 3.1416 or about 6¼ times the thickness of the material. For an easy fit, add a little more to this. This amount can best be determined from the experience of the layer out for the particular job in hand. In the case of a straight stack, with in and out rings, where there is no pressure upon the shell and the work is not to be water-tight,

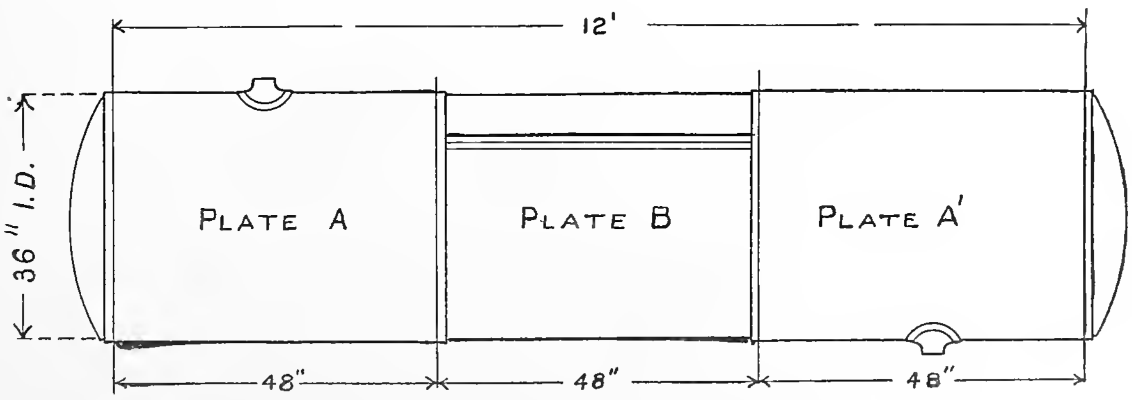


FIG. 10.

seven times the thickness of material can be added to the length of the inside ring for the length of the outside ring.

Bearing in mind the foregoing manner of determining the length of the rings of a cylindrical shell and the allowances to be made due to rolling the material, let us consider the layout of the shell of the pressure tank shown in Fig. 10. This tank is 36 inches diameter and 12 feet long, excluding the heads. It is to be made of three rings of 5-16-inch plate with double-riveted lap joints for the longitudinal seams and single-

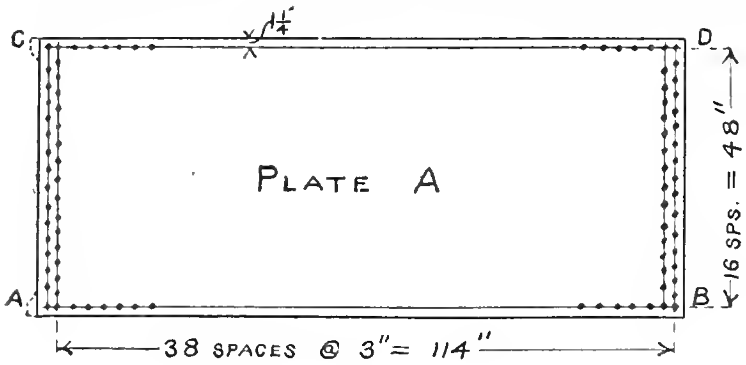


FIG. 11.

riveted lap joints for the circumferential seams, all rivets to be ¾ of an inch in diameter. The width of each ring as shown on the drawing is 4 feet between the center lines of the rows of rivets. Lay out the plates to dimensions taken through the center lines of the rivet holes, and afterward add the necessary amount for laps.

First, lay out one of the end or outside plates. As each ring forms a cylinder whose bases are at right angles with its axis the development will be a rectangle similar to the first development in Fig. 8. Therefore it will not be necessary to draw the parallel lines. The width of this plate between the centers of rows of rivets is 48 inches. The length must be computed from the diameter of the ring. The drawing indicates that the inside diameter of this ring is 36 inches. The circumference corresponding to a diameter of 36 inches is 113 1-16 inches.

$$\begin{array}{r} 3.1416 \\ 36 \\ \hline 188496 \\ 94248 \\ \hline 113.0976 \end{array}$$

113.0976 or 113 1-16 inches.

Add three times the thickness of the plate or three times 5-16, which equals 15-16. Therefore, the length of the plate between the centers of the rivet lines is 114 inches. Having found these dimensions lay out the plate as follows.

First, draw the line *AB* for the lower row of rivets 1¼ inches from the edge of the plate. Then measure from one end of the plate along the line *AB* 1¼ inches for the lap. From this point measure 1 15-16 inches for the second row of rivets. Now, lay off from this point along *AB* 114 inches as shown by the dimensions on Fig. 11. Measure back from this point 1 15-16 inches for the second row of rivets at this end of the plate. Draw the line *CD* 48 inches from *AB*. Now, square up the plate by the method previously explained and draw in the rivet lines for the longitudinal seams. Space in the rivet holes about 3 inches between centers. As the length of the circular seam is 114 inches, a 3-inch pitch will give just thirty-eight spaces in the circular seam.

The length of the longitudinal seam is 48 inches, so there will be sixteen equal spaces using the 3-inch pitch. As this seam is double riveted, the rivet holes should be staggered as shown in the detail Fig. 13. Care should be taken to see which end of the plate will come outside when the plate is

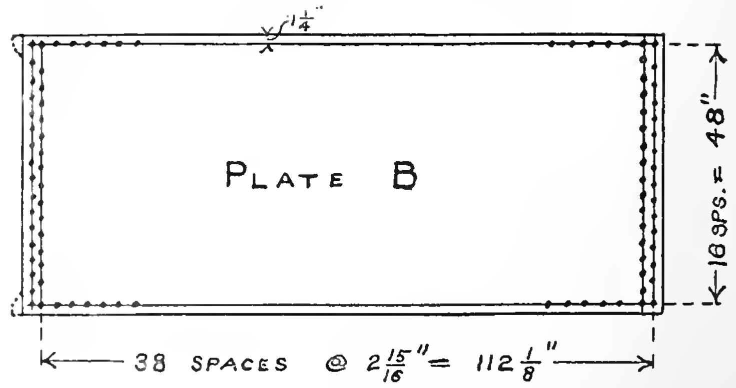


FIG. 12.

rolled up so that the outer row of rivets at this end of the plate can be spaced equally. The rivet holes in the other row may be conveniently located by setting the dividers to the diagonal pitch, and then with the centers of the holes, which have been equally spaced as centers, strike intersecting arcs as shown in Fig. 13. When the end of the plate comes between two other plates at the corners the plate should be drawn out thin or scarfed. As this plate is an outside ring, the

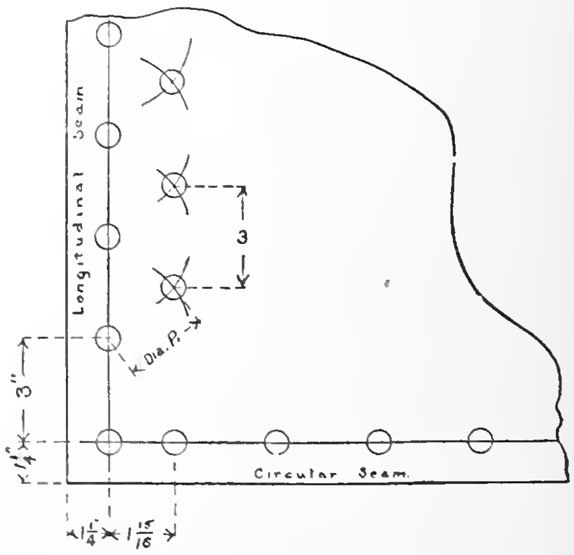


FIG. 13.

corners of the end which comes inside at the lap should be scarfed as indicated by the dotted lines in Fig. 11.

The layout of the inside ring is similar to that of the outside, except that the length between the centers of the rivet holes is less than that of the outside plate by six times the thickness of the material. As the plate is 5-16 inch thick, six times the thickness will be 1⅞ inches; therefore, the length of this plate should be 114 inches minus 1⅞ of 112⅛ inches. The pitch of the rivets in the circular seam will not be the same as in the outside plate, since the number of spaces must be the

same. As this is an inside ring, the corners of that end of the plate, which comes outside at the lap when the plate is rolled up, should be scarfed as indicated by the dotted lines in Fig. 12.

The layout of the heads has not been given in this article, neither have the nozzles in plates *A* and *A'* been located, as this layout was given simply to show the method of getting the sizes of the plates which form a cylindrical surface.

LAYOUT OF AN OPEN TANK.

Fig. 14 shows an open tank 6 feet wide by 4 feet deep (inside dimensions) and 15 feet long between the center lines of

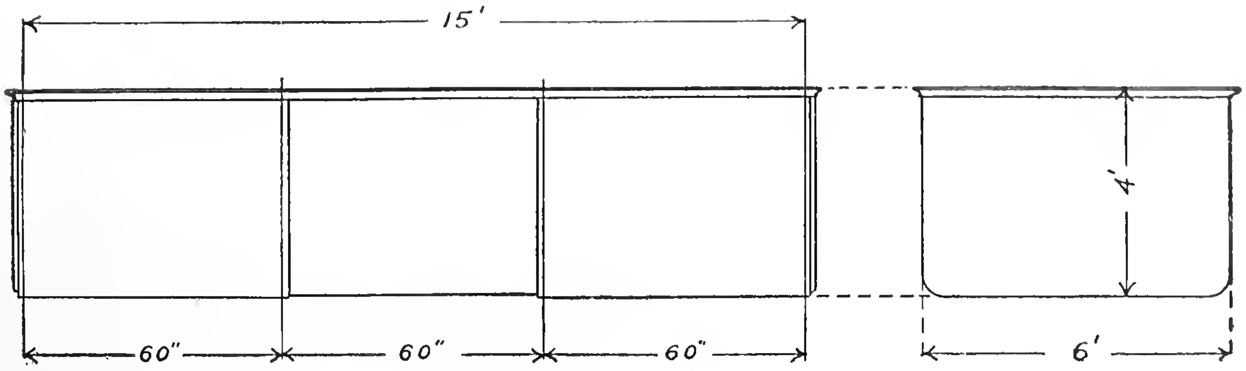


FIG. 14.

the rivet holes in the heads. This tank is to be made of three courses of ¼-inch plate joined together by single-riveted lap seams, the rivets being ⅝ inch in diameter. The radius of the curve at the corners of the tank is 6 inches. The heads are to be flanged.

First lay out one of the end or outside plates, a sectional view of which is shown in Fig. 15. It will be seen that the length of this plate is equal to 3½ feet (the length of the flat part of the plate at the side), plus one-quarter of the circumference of a circle of 6⅛ inches radius, plus 5 feet (the length of the flat portion of the plate at the bottom) plus one-quarter

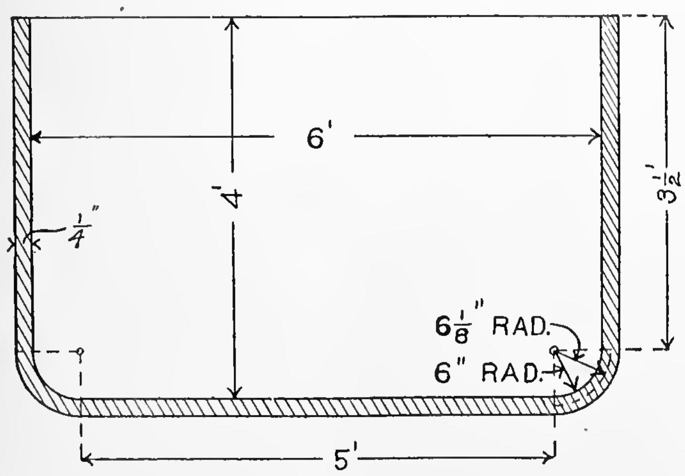


FIG. 15

of the circumference of a circle of 6⅛ inches radius, plus 3½ feet (the length of the straight portion of the other side). The length of the curved or cylindrical part must be computed as follows.

Since the inside radius at the corner is 6 inches and the thickness of the plate ¼ of an inch, the neutral diameter of the cylinder, of which this forms one-quarter of the surface, will be 12¼ inches. Therefore, the length of one-quarter of the circumference corresponding to this diameter will be

$$
\begin{array}{r}
3.1416 \\
12\frac{1}{4} \\
\hline
62832 \\
31416 \\
.7854 \\
\hline
38.4846
\end{array}
$$

$$\frac{38.4846}{4} = 9.6212'' \text{ or } 9\tfrac{5}{8}''.$$

Now, lay out the plate as shown in Fig. 16. As the rivets are to be ⅝ inch, the lap, which is usually 1½ times the diameter of the rivet, will be about 1 inch. Therefore, draw in a line 1 inch from the longest edge of the plate. Lay off 3½ feet or 42 inches from one end of the plate for the side; then 9⅝ inches for the curved portion; then 5 feet or 60 inches for the bottom, and then 9⅝ inches for the other corner, and then 3½ feet or 42 inches for the other side. Lay out the width of the plate 60 inches. Square up the ends and the flange lines to which the corners are to be rolled. The rivet holes should be spaced in at about 1⅞ inches between centers. Put in the first rivet hole 1 inch from the end of the plate, and then step off the spaces at about this pitch to the flange line at the

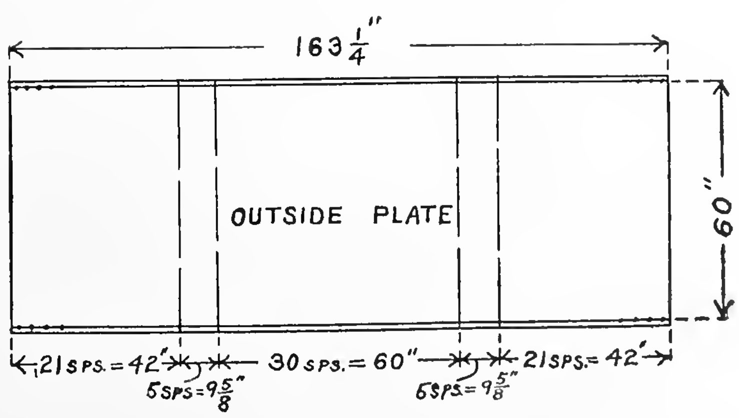


FIG. 16.

corner. The same spacing may be used on the other side. Then step off an even number of spaces in the curved part, changing the pitch if necessary, also step off the spaces on the bottom at as near the same pitch as possible.

For the inside plate, the only difference in the dimensions will be in the length of the curved part at the corner. The neutral diameter for this plate will be 11¾ inches, or the

neutral diameter of the outside plate minus twice the thickness of the material. One-quarter of the circumference of a circle 11¾ inches in diameter will be

$$
\begin{array}{r}
3.1416 \\
11\tfrac{3}{4} \\
\hline
31416 \\
31416 \\
23562 \\
\hline
36.9138
\end{array}
$$

$$\frac{36.9138}{4} = 9.2285'' \text{ or } 9\ 7\text{-}32''.$$

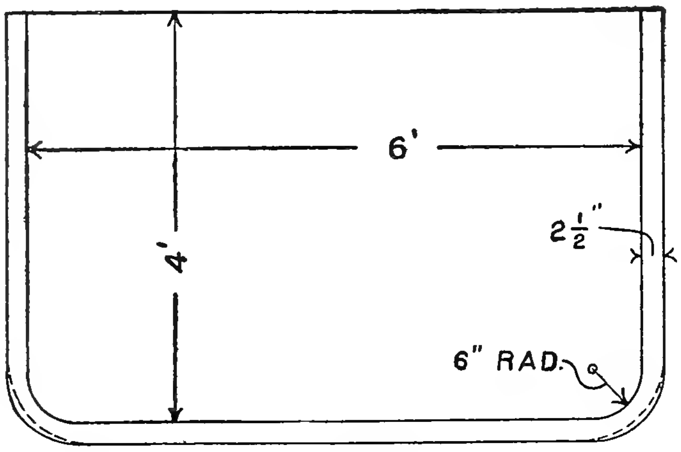


FIG. 17.

This gives us then 9 7-32 inches as the length of this part of the plate. The spacing of rivets in the flat portions of the plate will be the same as in the outside plate. In the curved portion the number of spaces must be the same, although the pitch will be different. As there were five spaces in this part of the outside plate there must be five spaces in this part of the inside plate, but the pitch will be about 1.85 inches instead of 1.92 inches.

To lay out the heads, first draw the flange line, making the head 6 feet wide and 4 feet deep, with a 6-inch radius at the

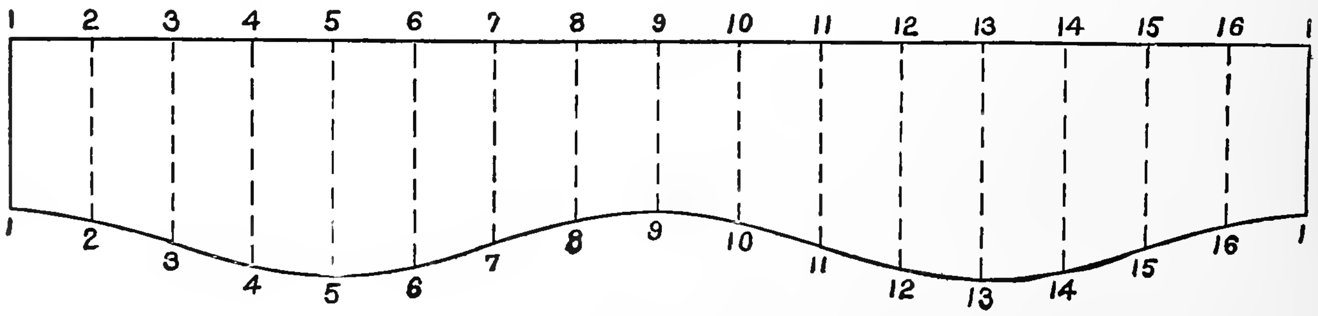


FIG. 19.

corners. We will assume that the flange is to be 3 inches deep. As the metal will be drawn down at the curved part of the flange, it will not be necessary to leave 3 inches to make this flange. Subtract from the depth of the flange twice the thickness of the plate, giving us 3 inches minus ½ inch, or 2½ inches as the distance from the flange line to the edge of the plate. At the corners the plate should be sheared off in some such manner as indicated by the dotted lines, Fig. 17, as there will be too much material in the corner when it is flanged over, and by cutting the plate, as shown, some of this will be removed. After the plate is flanged the rivet line can be drawn and the holes spaced to correspond with the holes in the adjoining plate.

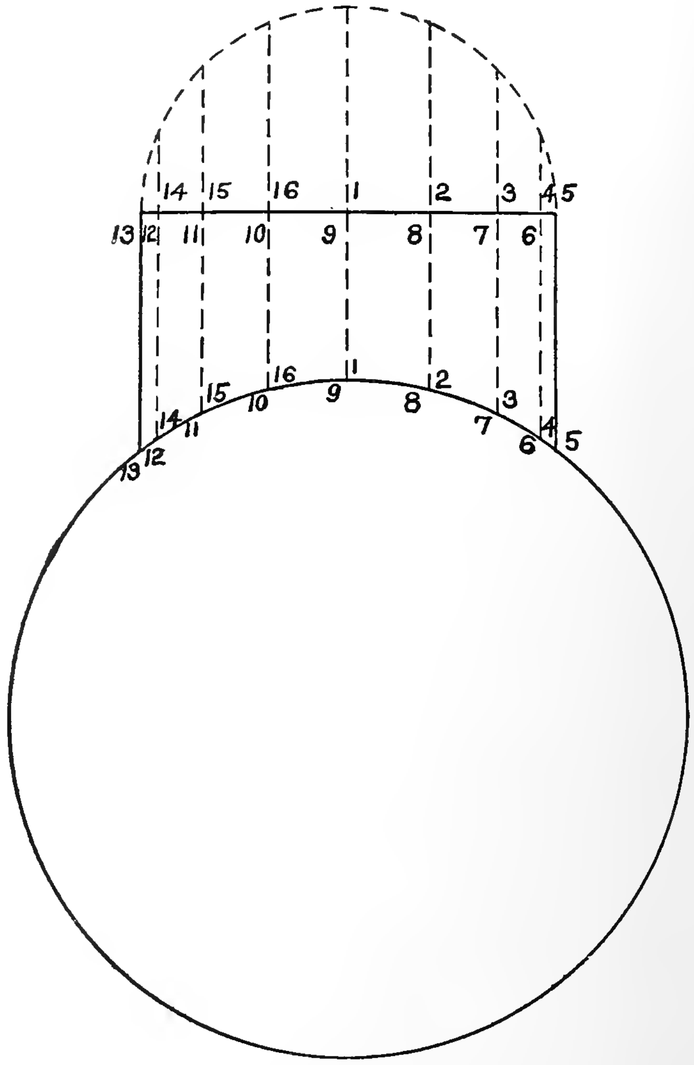


FIG. 18.

This tank will need angle-bars along the top edges to stiffen it. As these are simply straight bars, it will not be necessary to show how they are laid out.

While the foregoing problems are in themselves simple, they represent some of the common everyday work which an apprentice must learn to do accurately before attempting to lay out more complicated surfaces, where it will be necessary to make use of the principles of orthographic projection. Having mastered these elementary principles for finding the sizes of plate which are to be rolled to form cylindrical surfaces, he will then more readily understand the more complicated layouts which are to follow.

Problems frequently come up in both boiler and sheet-metal work in which it is necessary to find the development of the

surfaces of cylinders which intersect each other or are cut by plane or curved surfaces. One of the simplest of these problems is that in which two cylinders of the same or different diameters intersect at right angles, as shown in Fig. 18.

The development of the small cylinder, which is shown in Fig. 19, may be found in the following manner: Draw a plan or half-plan view of the cylinder and divide it into any convenient number of equal parts. In this case the half-plan is shown dotted just above the cylinder, with the semi-circumference divided into eight equal parts. Project these points of division down to the elevation and draw the parallel lines

the edge of the plate should be located at a distance below it sufficient to give the desired width of flange after flanging, or approximately the width of flange minus two times the thickness of the plate.

To get the development of the opening in the large cylinder at the line of intersection it would be necessary to draw a side elevation of Fig. 18; draw the parallel lines on the small cylinder, and then project the points 1, 2, 3, 4, etc., from the large cylinder across to the respective lines 1-1, 2-2, 3-3, 4-4, etc., in the side elevation. The lines which were used in projecting the points from one elevation to the other would of

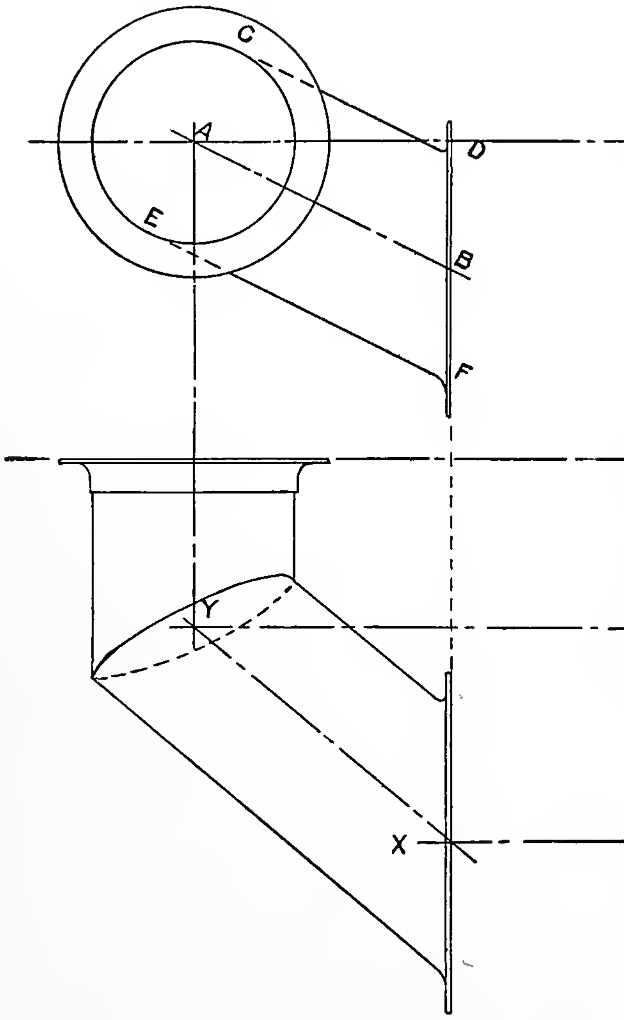


FIG. 20.

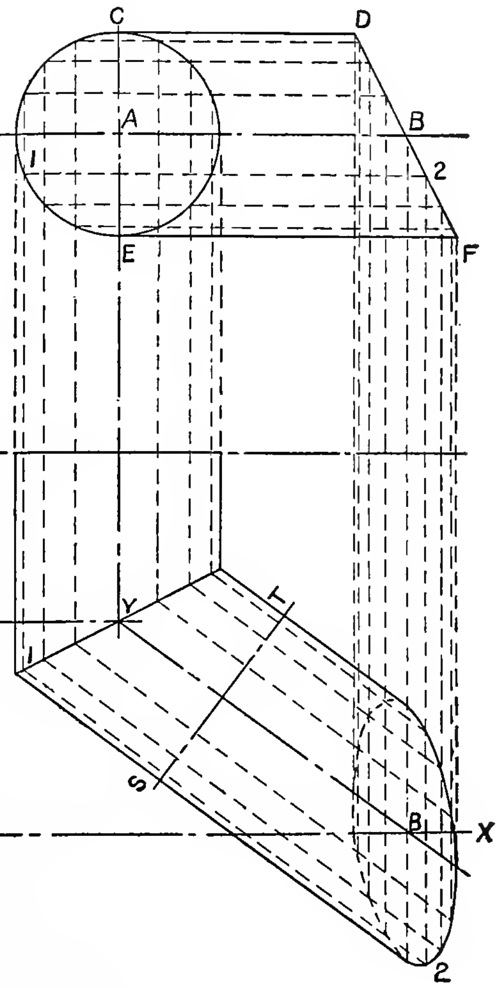


FIG. 21.

1-1, 2-2, 3-3, etc. Then lay out the line 1-1, Fig. 19, equal to the circumference of the cylinder. Divide 1-1 into sixteen equal parts to correspond with the divisions in the plan. Draw the parallel lines 1-1, 2-2, 3-3, 4-4, etc., at right angles to 1-1 at these points of division and lay off upon each its proper length as measured from the top of the cylinder in the elevation, Fig. 18, to the surface of the large cylinder at the line of intersection. A smooth curve drawn through these points defines that edge of the development.

If the small cylinder were to be made of a plate rolled to the proper diameter and flanged at the lower edge for a riveted joint to the large cylinder, it would be necessary to make the line 1-1 equal to the circumference corresponding to the mean diameter of the cylinder measured to the center of the plate. This would give the distance between the rivet lines and the laps, equal to 1½ times the diameter of the rivets should be added outside this. The lower edge of the development as shown in Fig. 19 would then be the flange line, and

course be parallel and might be used as the parallel lines in the development. These will not, however, be spaced equally on the circumference of the large cylinder, for as can be seen in Fig. 18, the spaces 1-2, 2-3, 3-4, etc., are unequal. Therefore care should be used in spacing them in a corresponding manner in the development.

In Fig. 20 is shown a cylindrical coal chute leading from a floor forward at an angle through a wall. Here we have two cylinders of the same diameter, intersecting at an angle and also one of the cylinders cut by a plane surface at an angle. In this problem it will be seen that the line of intersection of the two cylinders must be determined before the lengths of the parallel lines on the surfaces of the cylinders can be obtained. Furthermore, since the inclined section of the chute appears foreshortened in both the plan and elevation, the true lengths of parallel lines drawn upon its surface will not be shown in either plan or elevation.

The projection of the cylinders upon a vertical plane par-

allel to the axis of the inclined section will show the true lengths of all lines parallel to the axis of either cylinder. Such a view is shown in Fig. 21. The plan, Fig. 21, is exactly like the plan, Fig. 20, except that the axis of the inclined section has been taken parallel to the plane of the paper. Therefore, the distances *A B, C D, E F*, etc., Fig. 21, are equal, respectively, to the distances *A B, C D, E F*, etc., Fig. 20. In order to draw the elevation, Fig. 21, project the point *B* down from the plan to the line *X X*, locating one end of the axis of the cylinder. The other end of the axis may be projected over to the line *Y Y* from Fig. 20. Then the outline of the cylinder will be drawn parallel to this line.

The lower end of the inclined section will appear as a curve and must be determined as follows: Divide any cross-section of the cylinders, as the plan view of the vertical section, into a convenient number of equal parts, and from these points of division, draw lines parallel to the axis of the cylinder in both plan and elevation, lettering or numbering the corresponding lines to avoid confusion. Then to locate any point, as 2, in the elevation, project the point 2 from the plan down to the line 1-2 in the elevation. Do the same for each point at the lower end of the inclined section and then draw a smooth curve through these points, completing the elevation.

Since the true length of each of the parallel lines is shown

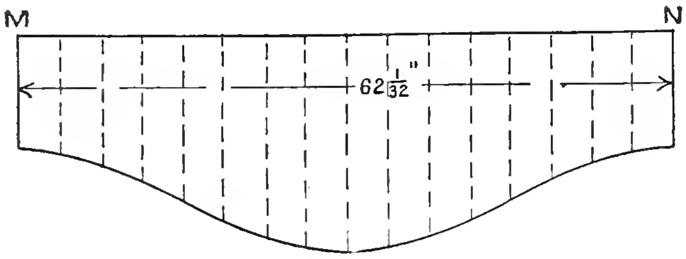


FIG. 22.

in the elevation, Fig. 21, the development of the two sections forming the chute may now be laid out in the usual manner. Assume that the outside diameter of the vertical section is 20 inches, and that the thickness of the plate is ¼ inch. Then the mean diameter of the vertical section will be 62 1-32 inches.

```
  3.1416
   19.75
 -------
  157080
 219912
282734
31416
 -------
62.045600" or 62 1-32"
```

Lay out the line *M N*, Fig. 22, for the top edge of the plate, 62 1-32 inches long, and divide it into 16 equal parts to correspond with the divisions in Fig. 21. Draw parallel lines at right angles to *M N* from these points; then on each of these lines lay out its length as shown in the elevation, Fig. 21. This will locate the flange line and the necessary amount for the flange must be added below this. In Fig. 22, both laps and flange have been omitted.

Since the vertical section fits inside the inclined section, the mean diameter of the inclined section will be 20¼ inches. The length of the plate will therefore be 63⅝ inches.

```
  3.1416
   20.25
 -------
  157080
 62832
62832
 -------
63.617400" or 63⅝"
```

As it is not necessary to have a close fit in this case, make this length 63¾ inches.

As there is an irregular cut at each end of the plate, take a cross-section at any point in the cylinder as the section *S T*, and measure the length of each of the parallel lines from this section in both directions. Lay out the line *S T*, Fig. 23, 63¾ inches long; divide it into sixteen equal parts, drawing lines at right angles to *S T* at these points; and lay off the lengths of these lines as measured from the elevation, Fig. 21. This gives the development of this plate to the rivet and flange lines.

Without giving further examples it will be seen that the development of any cylindrical surface can be obtained in the manner above described if a projection of the solid on a plane parallel to its axis can be drawn. If the axes of two or

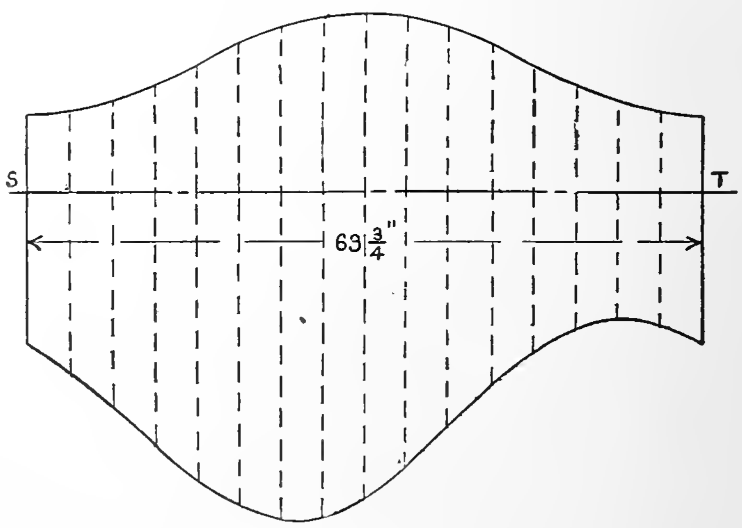


FIG. 23.

more intersecting cylinders lie in the same or parallel planes, such a projection may be obtained. If their axes do not lie in the same or parallel planes, it will be necessary to find the true lengths of the parallel lines on each solid separately.

THE LAYOUT OF ANGLE-IRON RINGS.

Where it is necessary to bend bars of angle-iron into the form of a circle or ring in order to fit around a circular tank or pipe, it is a much easier and quicker job to lay out the bars and punch the rivet holes before the iron is bent. This can be done very accurately, and is by no means a difficult job of laying out. It is necessary, however, to know some rule by which the exact length of the bar may be obtained, so that when it is bent either the inside or the outside diameter of the ring, depending upon whether it is an inside or outside angle, will be the required amount.

There are two good working rules which may be used and

will apply equally well whether the bar is bent cold or hot. For an outside angle, that is, with the heel of the angle toward the center of the circle, the diameter to be used in computing the length of the bar will be as follows: Using the figures indicated in Fig. 24, and calling the inside diameter of the ring D, then the proper diameter to use will be

$$D + 1/3\,W + T.$$

That is, it is the inside diameter of the ring plus one-third the

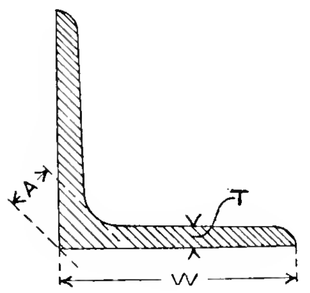


FIG. 24.

width of the angle plus the thickness of the angle measured at the line of rivet holes. The length of the bar will, of course, be this diameter multiplied by 3.1416. For an inside angle, if

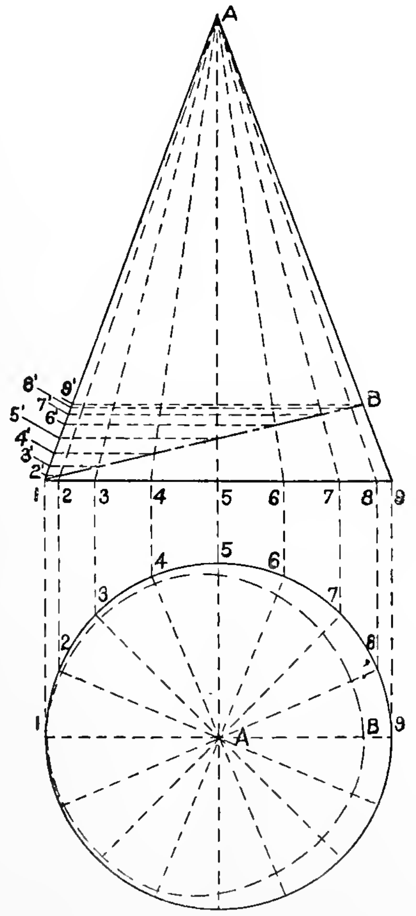


FIG. 25.

D equals the outside diameter of the ring, the diameter to be used for computing the length should be

$$D - (1/3\,W + T).$$

The length will, therefore, be 3.1416 times this amount.

Another good working rule is as follows: For outside angles the diameter to be used in computing the length should be $D + 2A$ where D is the inside diameter of the ring and A is the thickness of the root of the angle measured diagonally as indicated in Fig. 24. For inside angles, if D is the outside diameter of the ring, then the diameter to be used in computing the length should be $D - 2A$.

Some small allowances are frequently made, due to the stretch in the bar caused by punching the holes, but this is

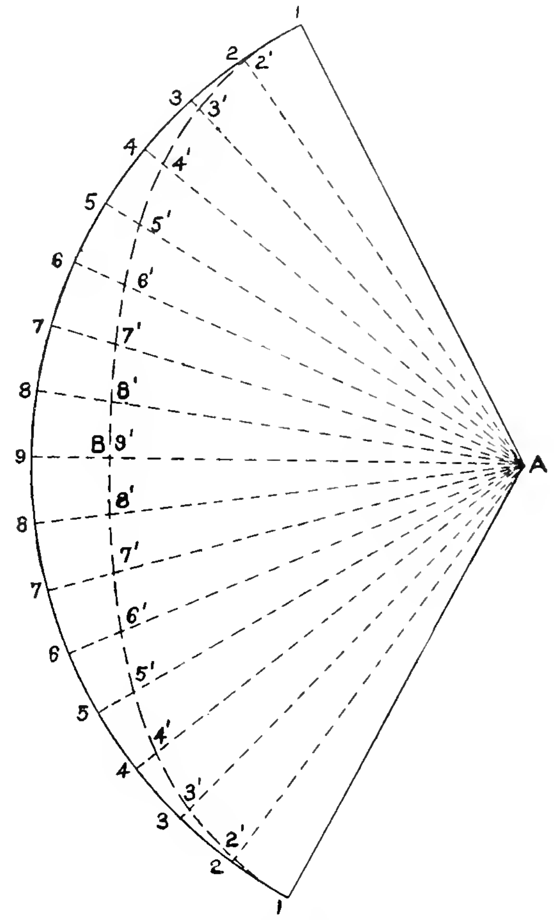


FIG. 26.

best determined by observation, as no definite allowance can be stated. It would be small at most. The bars may be bent to a comparatively short radius after the holes have been punched without tearing the metal from the rivet holes to the edge of the bar, or destroying the shape of the holes, by inserting in the holes the small pieces which have been punched

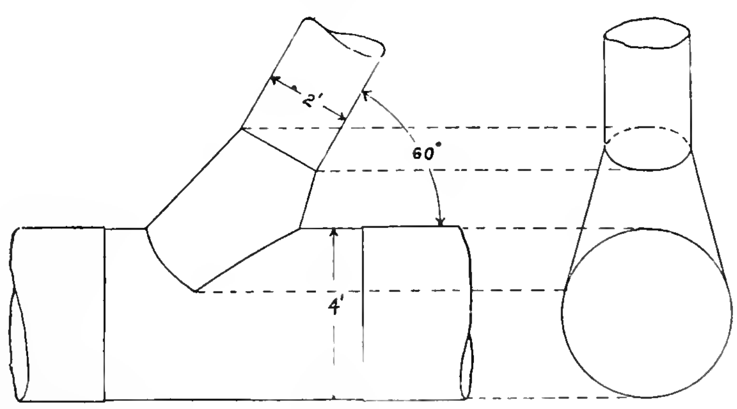


FIG. 27.

out. These will tend to keep the holes perfectly round, and the small pieces may easily be knocked out after the bar is bent.

CONICAL SURFACES.

Conical surfaces may be developed by a method somewhat similar to that used with cylindrical surfaces. A cross section of the cone is divided into a number of equal parts, and lines are drawn on the surface of the cone from these

points to the vertex. For instance, in Fig. 25 the circumference of the base of the cone is divided into sixteen equal parts, and lines are projected from these points of division to the base of the cone in the elevation. These points are then connected with the vertex of the cone *A*. It may then be seen that the surface is divided into a number of triangles, the sides of which are elements of the cone, and therefore equal to the distance *A*1, and the bases equal to the length of the equal divisions shown in the plan, that is, the distances 1-2, 2-3, 3-4, 4-5, etc. This side of the triangle is, of course, the arc of a circle since each point in the circumference of the base is equidistant from the vertex of the cone *A*. The circumference of the base of the cone, when laid out in the development, will then be the arc of a circle drawn with radius *A*1. This development is shown in Fig. 26.

If the base of the cone had been inclined, as shown by line 1*B* in the elevation of Fig 25, it would be necessary to lay out the development as shown by the outline in Fig. 26, and then measure the length of each of the elements which have been drawn on the surface of the cone from the point *A* to the base 1*B*. It will be noted that in the elevation, Fig. 25, the true length of only two of these elements is shown, that is, the elements *A*1 and *AB*. The length of the remaining elements may be found by projecting the points at which the line 1*B* cuts the lines *A*-2, *A*-3, *A*-4, etc., over to either the line *A*-1 or *A*-9, and then measuring the distances *A*2′, *A*3′, *A*4′, etc. These distances have been laid off on the corresponding lines in Fig. 26, locating the dotted line 1-9′-1, which is the development of the circumference of the inclined base of the cone 1*B*.

THE INTERSECTION OF A CONE AND CYLINDER AT AN ANGLE OF 60 DEGREES.

In Fig. 27 is shown a cone connecting a 2-foot with a 4-foot pipe. The 2-foot pipe branches from the larger one at an angle of 60 degrees. The end elevation shows that the sides of the connection are tangent to the cross-section of the large pipe. The problem is to find the development of the conical connecting piece and the section of 4-foot pipe which it intersects.

The construction, by means of which this is done, is shown in Fig. 28. This is shown at a larger scale for the sake of clearness. Produce the sides 4*c* in the end elevation until they intersect at the vertex of the cone *A*. Project this point over to the side elevation and the point where the horizontal line *A A* intersects the axis of the branch pipe will be the side elevation of the vertex. Take a cross-section of the cone through the line 4-4 in the side elevation. The diameter of this section is the distance 4-4. Draw *B C* in the side elevation perpendicular to *A*-4 through the point 4, making it equal to the length of the diameter 4-4. Connecting *B* and *C* with *A* gives the outline of the side elevation of the cone.

On *B C* as the diameter draw a half view of the cross-section of the cone, and divide it into six equal parts. A greater number of divisions should be taken in actual practice, but only six were used in this problem to avoid confusing the figure. Project these points of division to the line *B C* and connect the latter points with the vertex *A*. Since the axis of the cone in the end elevation is inclined downward and backward, in order to draw the equally spaced elements in this view, it will be necessary to revolve the cone about the vertex *A* until the axis is vertical or in the position indicated by the dotted lines *A M N* in the side elevation. The cross-section of the cone through 4-4 will then be represented in the end elevation by the line *S T*, which may be divided in a similar manner to the line *B C*. The points of division should then be projected upward until they intersect horizontal lines drawn from the corresponding points on the line *B C* in the side elevation. This will give the end elevation of the cross-section of the cone in the inclined position. This is shown by the dotted ellipse. Join the points thus found in the cross-section with the vertex *A*. In Fig. 28 the elements on the front of the cone are shown to the left of the center line and those on the back are shown to the right in order to avoid confusion in the figure.

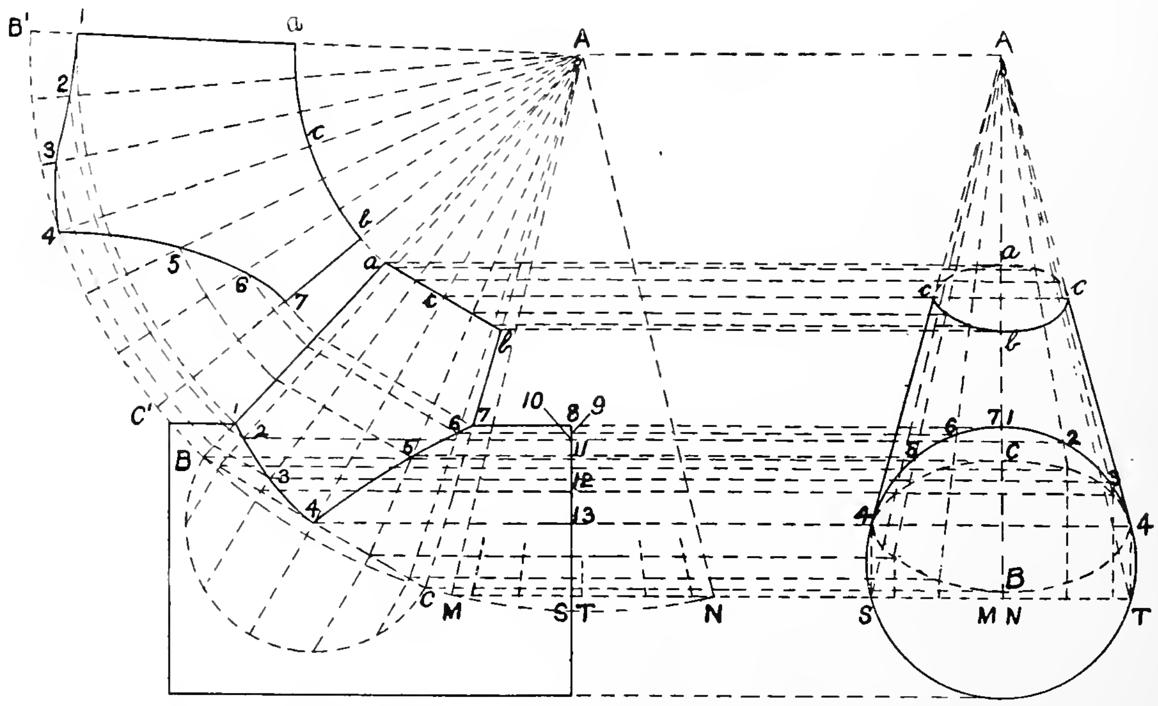


FIG. 28.—SIDE ELEVATION AND DEVELOPMENT OF CONE. END ELEVATION.

Number the points where these lines intersect the circumference of the 4-foot pipe in the end elevation 1, 2, 3, 4, 5, 6 and 7; then project these points to the corresponding elements drawn on the surface of the cone in the side elevation, thus locating the line of intersection between the cone and the large pipe.

Having obtained this line of intersection, the cone may be developed in the usual way. The half pattern of the cone is shown just at one side of the side elevation. The arc *B' C'* is made equal in length to half the circumference of the cross-section *B C*. *B' C'* is then divided into the same number of equal parts as the semi-circumference of the cross-section, and these points are connected with the vertex *A*. The top edge of the connection is the arc of a circle, whose radius is *A* a. The bottom edge of the connection is found by projecting the points 2, 3, 4, 5 and 6 to the line *A B* and then by laying off along the corresponding lines in the development the distances measured from *A* to these points.

The development of the section of large pipe intersected by the cone is shown in Fig. 29. The width of the plate *R H* corresponds to the line *R H* in Fig. 28. The length of the plate *R O* is made equal to the circumference of the pipe, *i. e.,* of a circle 4 feet in diameter. Square up the plate and locate the center line 8-1; then on either side of 8, the distances 8-9, 8-10, 8-11, 8-12 and 8-13 are laid off equal to the distances 1-7, 1-2, 1-6, 1-3, 1-5 and 1-4 in the end elevation, Fig. 28. The distance 8-7 measured from the side elevation, Fig. 28, is then laid off along the line 8-1. Similarly the distances 9-6, 11-5, 13-4, 12-3, 10-2, 8-1, measured from the side elevation, are laid off on their respective lines as indicated by the numbers. A smooth curve through these points is then the developed line of intersection. The proper amount for laps and flanges should of course be added on both patterns, the amount depending on the thickness of material, size of rivets, etc.

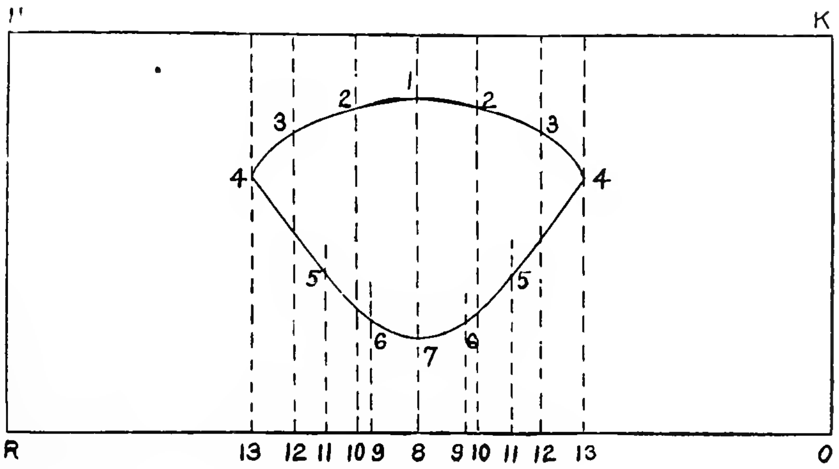


FIG. 29.

CONICAL SURFACES WHERE THE TAPER IS SMALL.

There are many cases in boiler making where it is necesary to lay out a plate which, when it is rolled up, will have the form of the frustum of a right circular cone, the taper of which is very slight. An example of this is shown in Fig. 31, where there is little difference between the diameters of the upper and lower bases of the frustum. This means that the slant height of the cone is very large. In the case of Fig. 31 it would be about sixty.

The layout of such a plate where the slant height is not too great to be used as a radius, is shown in Fig. 30. Of course, the upper and lower edges of the plate are arcs of circles drawn from the same center with a radius equal to the distance of the respective bases from the apex of the cone. The curved lines *ATB* and *CD* are, of course, equal in length to the respective circumferences of the two bases. Now, it will be seen that where the distance *AO* is too great to be used in the shop when laying out the plate full size; that is, if it were 30 or 40 feet, the plate might be laid out by drawing the Fig. *ACDB,* if the distance *ST*, commonly known as the rise or camber of the sheet, can be found.

The distance *ST* is often called by boiler makers the versed sine, without much knowledge of what this function is. In reality the versed sine is a trigomometric function of an angle, and in the case of Fig. 30 the ratio $\dfrac{ST}{OB}$ is the versed sine of the angle *SOB*. The distance *ST* itself should not be called a versed sine, and the versed sine of the angle *SOB* will never equal the distance *ST* except when the radius *OB* is unity. If the length of the radius *OB* is known the distance *ST* may be found by multiplying *OB* by the versed sine of the angle *SOB*.

This distance, however, may be found graphically as well as by calculation, thus enabling one to lay out the sheet without striking in the curves *CD* and *AB* from the apex of the cone. There are many different methods for laying out this form of sheet, and most of them are absolutely correct. Some few are only approximately correct, but since the taper of the ring is always small, the camber or distance *ST* is always small, and, therefore, the approximate method will be sufficiently accurate for ordinary purposes.

Two methods in common use for this layout are given herewith. Consider the frustum shown in Fig. 31, whose height is 12, the diameter at the top being 8 and that at the bottom being 10. The length of the sheet along the top edge will be the circumference of a circle whose diameter is 8, or $3.1416 \times 8 = 25.14$. The length of the bottom edge of the sheet is the circumference of a circle whose diameter is 10, or $3.1416 \times 10 = 31.416$. The width of the sheet must be com-

puted, since the height of the frustum between bases is given. The width of the sheet or the slant height of the frustum is the hypotenuse of a right triangle, one leg of which is 12 and the other one-half the difference between the diameters of the lower and upper bases, or $\frac{1}{2}(10 - 8) = 1$. Therefore, the width of the plate equals $\sqrt{12^2 + 1^2} = \sqrt{145} = 12.04$.

Referring to Fig. 32, it will be seen that we now have the following dimensions:

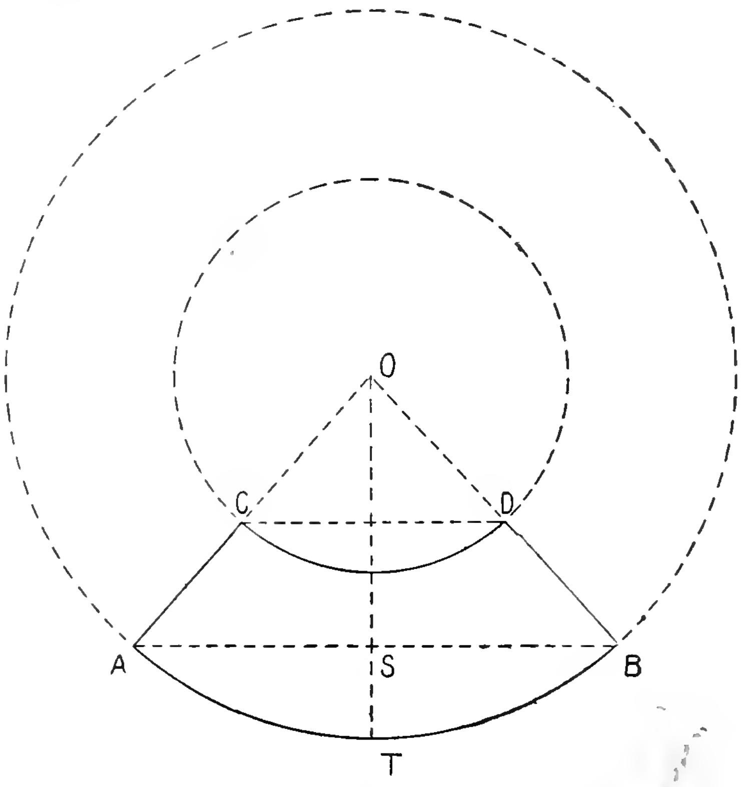


FIG. 30.

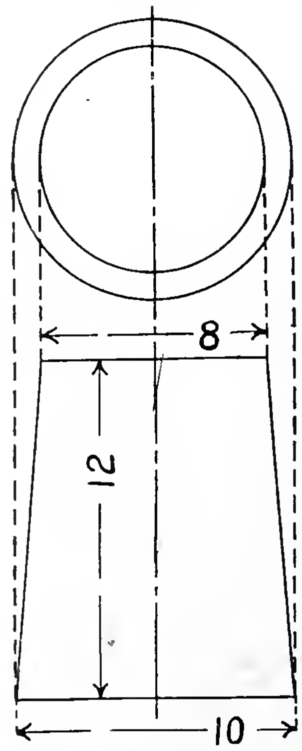


FIG. 31.

The length of the top edge of the plate $= 25.14$
The length of the lower edge of the plate $= 31.416$
The width of the plate $= 12.04$

In order to lay out Fig. 32 we must know the distance between the upper and lower edges. This will be found from the

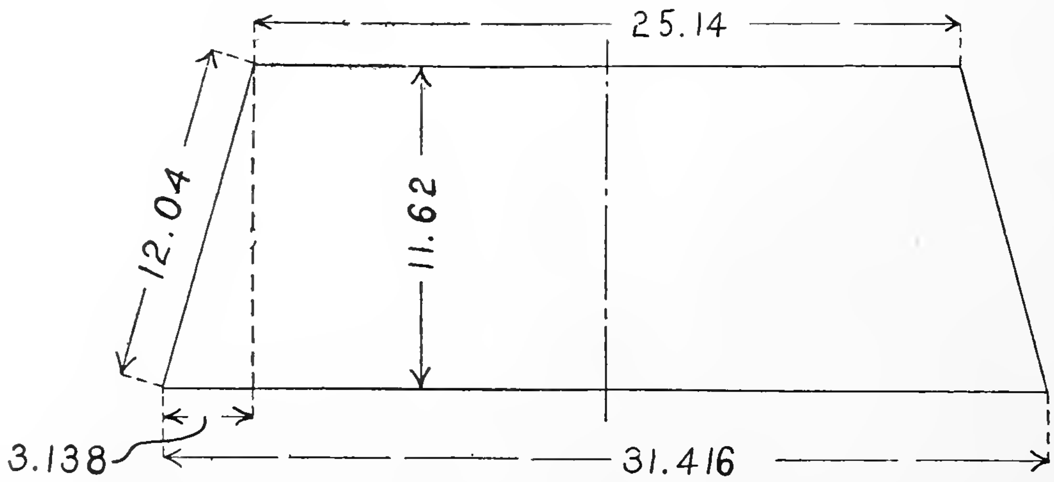


FIG. 32.

right triangle shown dotted at the left of the figure, or it is equal to the $\sqrt{12.04^2 - 3.138^2} = 11.62$.

Having found these dimensions the diagram *ABDC*, Fig. 33, may be laid out according to them. It is then necessary to construct on the lines *AB* and *CD*, as chords, the arcs of the circles, which are the true development of the upper and lower edges of the plate. It, therefore, becomes necessary to find the distance *OE* or the camber of the plate. To do this, with a straight edge and square, square up from *O* the center of the line *CD*, the line *OS* to the line *AC*. With *O* as a center set the trams to the line *OS* and draw an arc from *S* to the line *CD*. Find the middle point of this arc and draw the line *OT* through it. Then the distance *TC* is equal to the required camber of the plate, and may be laid off from *O* to *E*. Care should be taken to use the distance *TC* and not the distance *ST*, since the two are unequal, especially when the camber is large. The distance *ST* varies by an appreciable amount from the true camber.

Having found the point *E*, we now have three points on the curve, viz.: *C*, *D* and *E*. To get additional points on the curve divide the distance *OE* by 16, and multiply the result by 7, 12 and 15, respectively. Then divide the lines *CD* and *AB* into eight equal parts, and draw dotted radial lines to these points. Then along these lines, below the line *CD*, lay off the three distances just computed. Through these points a smooth curve can be drawn, and then the true length of this edge of the plate, which was found to be 31.416, may be measured off along it. This will bring the ends of the plate in

towards the center E a slight amount, since the length of the curve measured from C to D is slightly longer than 31.416.

The development of the upper edge of the plate may be found by setting the trams to the width of the sheet 12.04, and laying off this distance along the dotted radial lines from the lower edge of the plate. Draw a smooth curve through these points and make its length equal to the length of the top edge of the plate 25.14.

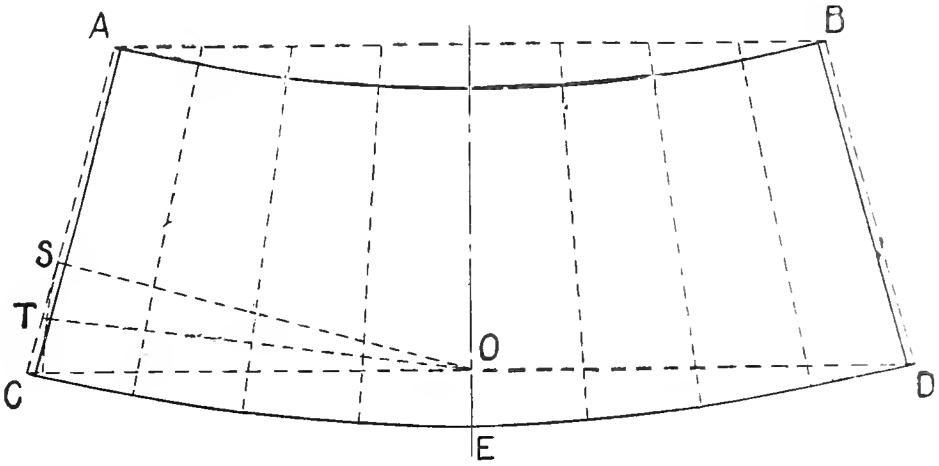


FIG. 33.

In Fig. 34 a second method of laying out a tapered sheet is shown. The Fig. $ABDC$ corresponds to the diagram $ABDC$, Fig. 33. Square up the line EF at the middle point of the line CD. Then locate any point as the point 1, equidistant from the lines EF and BD. This may be done by drawing a line parallel to EF at a distance from EF less than half ED, and then by drawing a line parallel to BD at the same distance from BD. The point where these two lines intersect is, of course, equidistant from the lines EF and BD. This is shown by the circle which has been drawn from 1 as a center, and which is tangent to both of these lines. With 1 as a center, set the trams to the distance $1D$, and strike an arc intersecting the line EF at E; also with 1 as a center, set the trams to the distance $1B$ and strike an arc intersecting EF at the point F. The point E is one point in the curve of the lower edge of the plate, and similarly the point F is one point in the curve of the upper edge of the plate.

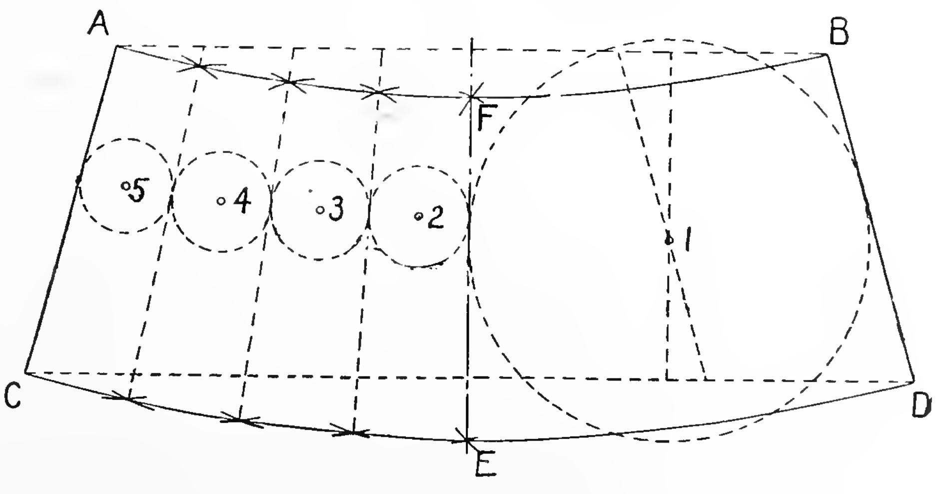


FIG. 34.

It will be necessary to locate several other points in the curve in order to determine it exactly. To do this, divide the lines AB and CD into eight equal parts, and through the points of division draw radial lines. Only those to the left of EF have been shown in Fig. 34. Then in the manner previously described for finding the point 1, determine the points 2, 3, 4 and 5, each of which is equidistant from the two sides of the respective figure in which it is located. Then, beginning with the point 5, set the trams to the distance $5C$, and with 5 as a center strike an arc intersecting the first dotted line; also set the trams to the distance $5A$, and with 5 as a center, strike an arc intersecting the dotted line for the upper edge. Then with 4 as a center, setting the trams to the distance from 4 to the intersection of the arcs just drawn with the first dotted line, strike the arcs intersecting the second dotted line, and repeat this process for the points 3 and 2. Then the curve, which is the true development of the edge of the plate, may be drawn through these points. The points 2, 3, 4 and 5 may be taken anywhere within their respective figures so long as they are equidistant from the sides of the figure.

With the second method just described, it is unnecessary to compute the dimensions shown in Fig. 32 and draw the diagram $ABDC$, Fig. 34, since the curve may just as well be drawn on Fig. 31 at once. In this case the side elevation, Fig. 31, should be considered in the same way as the diagram $ABDC$, Fig. 34. The curves, which are constructed to replace the upper and lower edges, will, however, be too short for the entire development of the plate. The curves may be continued beyond the side elevation, Fig. 31, by constructing on either

side other figures exactly like the side elevation of the frustum. If one such figure is constructed on each side, the curve will then be increased just three times, which is nearly the required length, since the length of the curve is 3.1416 times the diameter of the base of the cone.

A NINETY-DEGREE TAPERING ELBOW.

The problems on the preceding pages showed several different methods for laying out conical surfaces where the taper of the cone was so small that the surface could not be developed full size by the usual method of using the slant height of the cone as a radius. These methods may often be applied with slight variation to the development of regular conic surfaces where triangulation is usually employed, thus saving both time and unnecessary labor. A case of this kind is that of the 90-degree elbow shown in Fig. 35, where it is desired to construct an elbow which shall have a regular taper from a section whose diameter is *AC* to a section whose diameter is *GE*.

It is first necessary to draw a side elevation of this elbow in such a way that the sections will have a regular taper, that is, so that if the separate sections were turned about and placed one on the other, the center lines *BP*, *PI* and *IF* forming one continuous straight line, the resulting figure would be the frustum of a cone. To do this draw the line *AD* and at *D* square up the line *DG* at right angles to *AD*. With *D* as a center, and the trams set to a radius *DB*, strike the arc *BLF*, which curve the elbow is to follow. Divide the quarter circle *BLF* into two equal parts at the point *L*, then draw the line *DL*, and at *L* square up the line *PI* at right angles to *LD*. *PI* will then be tangent to the quarter circle and will be the center line of the middle section of the elbow. At *B* square up the line *BP* at right angles to *AD*, and similarly at *F*, square up the line *FI* at right angles to *DG*. The lines *BP*, *PI* and *IF* are then the center lines of the three sections of the elbow.

To draw the outline of the sections it is necessary to know the diameter of the sections at the points *P* and *I*, which are the intersections of their center lines. Since the taper is regular, and the center section has twice the length of the end sections, the diameter of the cone at the point *P* would be the diameter *GE* + ¾ the difference between *AC* and *GE*. With *P* as a center and with this diameter as just computed, draw the arcs *aa*. Similarly the diameter of a cross-section of the cone at the point *I* would be the diameter *GE* + ¼ of the difference between *AC* and *GE*. With *I* as center, and with this diameter draw the arcs *bb*. Then draw the lines *AN* and *CO* from *A* and *C*, respectively, tangent to the arcs *aa*; also draw the lines *NH* and *OJ* tangent to the arcs *aa* and *bb* and the lines *GH* and *EJ* from *G* and *E*, respectively, tangent to the arcs *bb*. Draw *NO* from the intersection of the sides *AN* and *NH* to the intersection of the sides *CO* and *OJ*; likewise draw *HJ* from the intersection of the lines *NH* and *GH* to the intersection of the lines *OJ* and *EJ*. *HJ* and *NO* are then the miter lines of the sections. This completes the side elevation of the elbow.

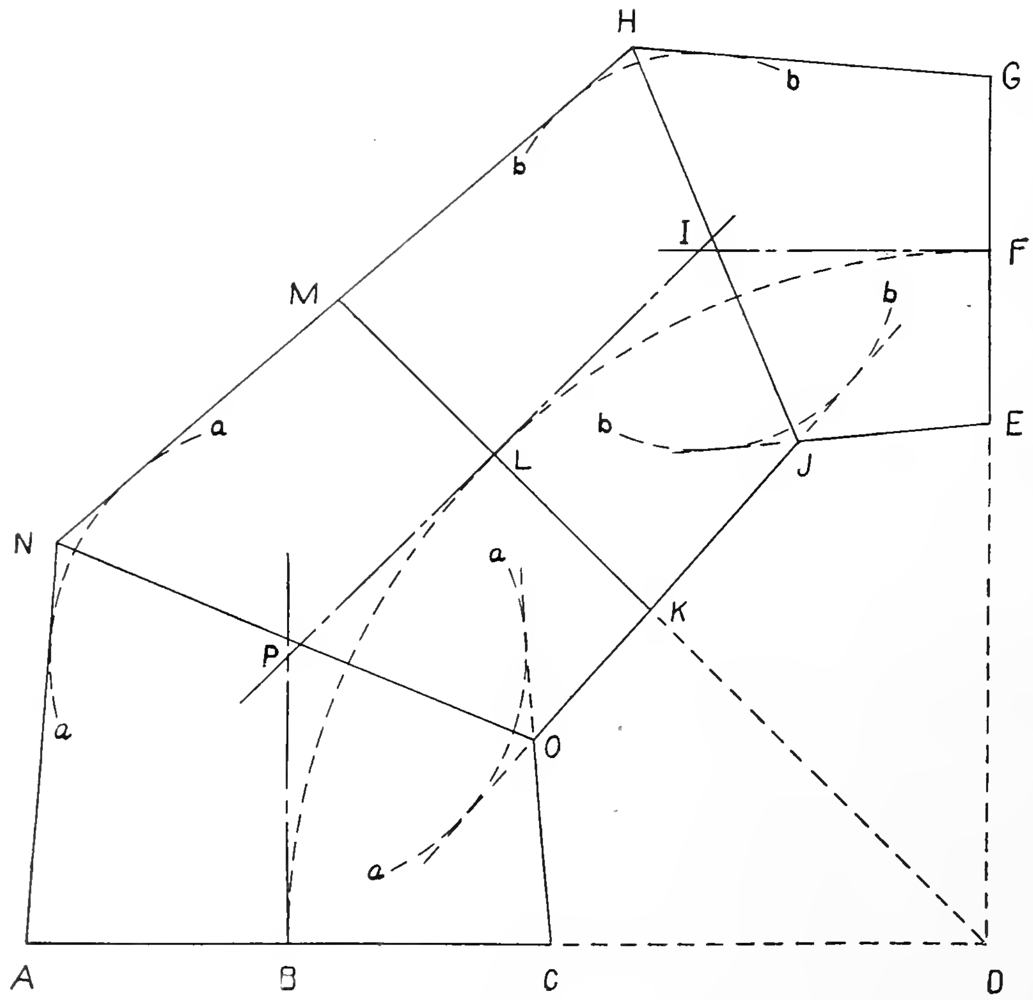


FIG. 35.

The elbow is now made up of four similar sections (the center section may be divided into two parts at the line *MK* and each part developed separately). Since the layout of all

of these sections is accomplished in a similar manner, using, of course, the proper dimensions for each as determined from the side elevation. we will take up in detail the patterns for only one section; as, for instance, the section *ANOC*. This section is shown at *AFEC*, Fig. 37. Divide the section into two parts by means of the line *BE*, which is parallel to the base *AC*. The section *ABEC* is then the frustum of a right circular cone and may be laid out in the usual manner. Having found the development of the section *ABEC*, the portion *BFE* can be easily added to it. The procedure is as follows:

To lay out the section *ABEC*, Fig. 37, find the circumferences corresponding to the diameters *AC* and *BE*. It will be necessary to lay out only one-half of the pattern, since the two halves are exactly alike. Therefore, in Fig. 36, draw the line *CD* equal to one-half the circumference of the base *AC*, Fig. 37. Also draw the line *AB* equal to one-half the circumference of the base *BE* at a distance from *CD* equal to *AB*, Fig. 37, the slant height of the frustrum. Draw the lines *AC* and *BD* and then from *O*, the center of *CD*, square up the line *OP* at right angles to *AC*. Bisect the angle *COP* with the line *OS*. Then the distance *SC* measured along the line *AC* is the camber of the sheet. Lay off *OX* equal to *SC*. Divide the lines *CD* and *AB* each into 8 equal parts and draw the dotted lines, as shown, through the corresponding points in each base. Divide the distance *OX* by 16 and multiply the quotient by 7, 12 and 15, respectively, giving the camber to be laid out on each of these dotted lines. Having determined the curve *CXD* at the lower edge of the plate, set the trams to the distance *AC*, the width of the plate, and lay off this distance along each of the dotted lines from the curve *CD*, locating the upper edge of the plate *A4B*. Make the length of the curves *CXD* and *A4B* correspond exactly to the semi-circumferences of the bases *AC* and *BE*, respectively, Fig. 37.

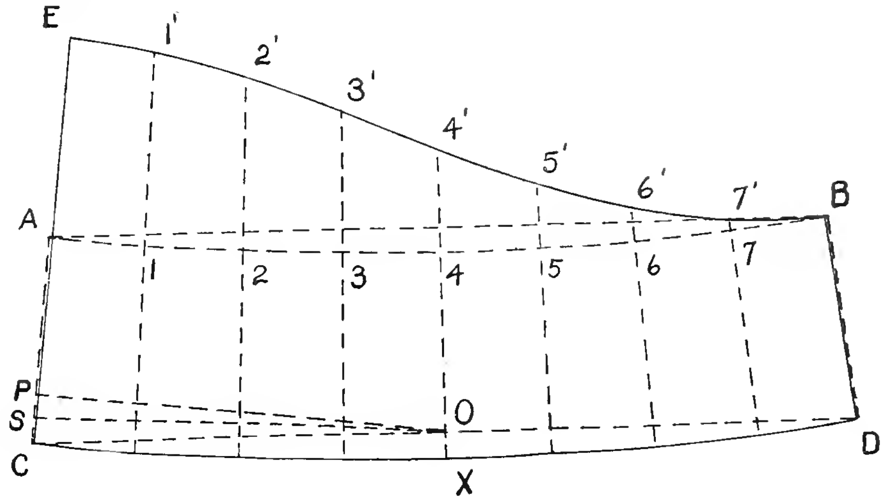


FIG. 36.

Returning to Fig. 37, draw a half-plan view of the bases *AC* and *BE*. Divide the semi-circumference of each into the same number of equal parts into which the lines *CD* and *AB*, Fig. 36 were divided. Project these points of division to the lines *AC* and *BE* and through the corresponding points on these two lines draw the dotted lines as indicated, producing them to intersect the line *FE*. It will be seen that we now have drawn on the side elevation of the section the equally spaced lines which have been drawn in the pattern and it is only necessary to lay off along these lines in the pattern the distances as measured from the cross-section *BE* to the miter line *FE* in the side elevation. Since this is the side elevation of a cone, the points at which these lines intersect the miter line should be projected across to the line *AF* in order that their true lengths may be measured. Then lay off 1 1′, 2 2′, 3 3′, etc., in the pattern equal, respectively, to the distances *B*1, *B*2, *B*3, etc., as measured from Fig. 37. Draw a smooth curve through the points *E*, 1′, 2′, 3′, 4′, 5′, 6′, 7″, *B* and the half pattern for the section is complete.

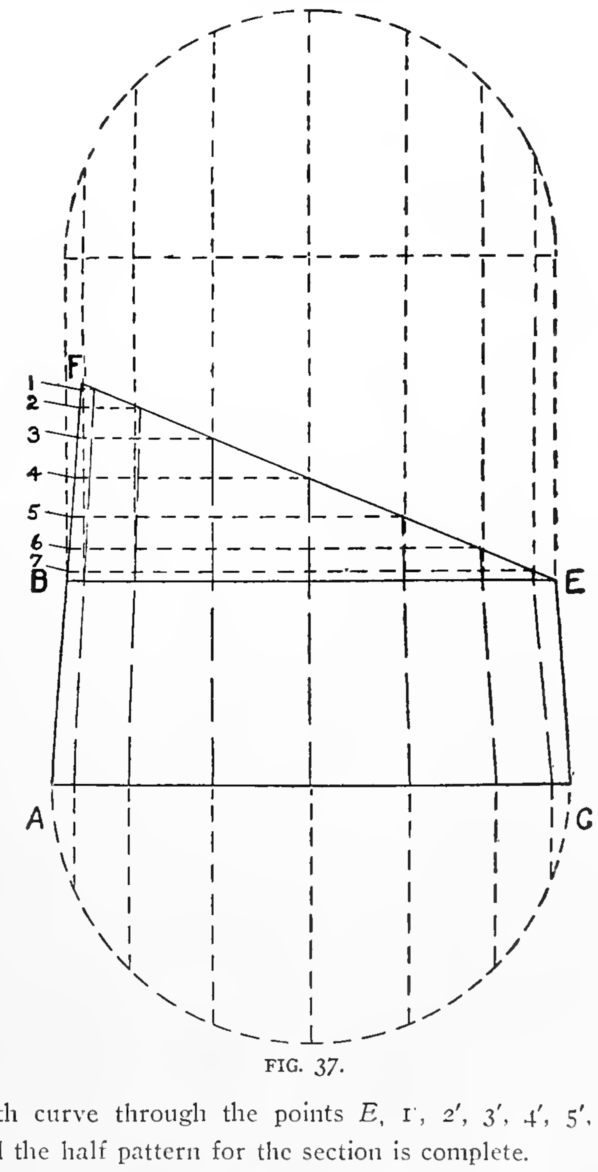
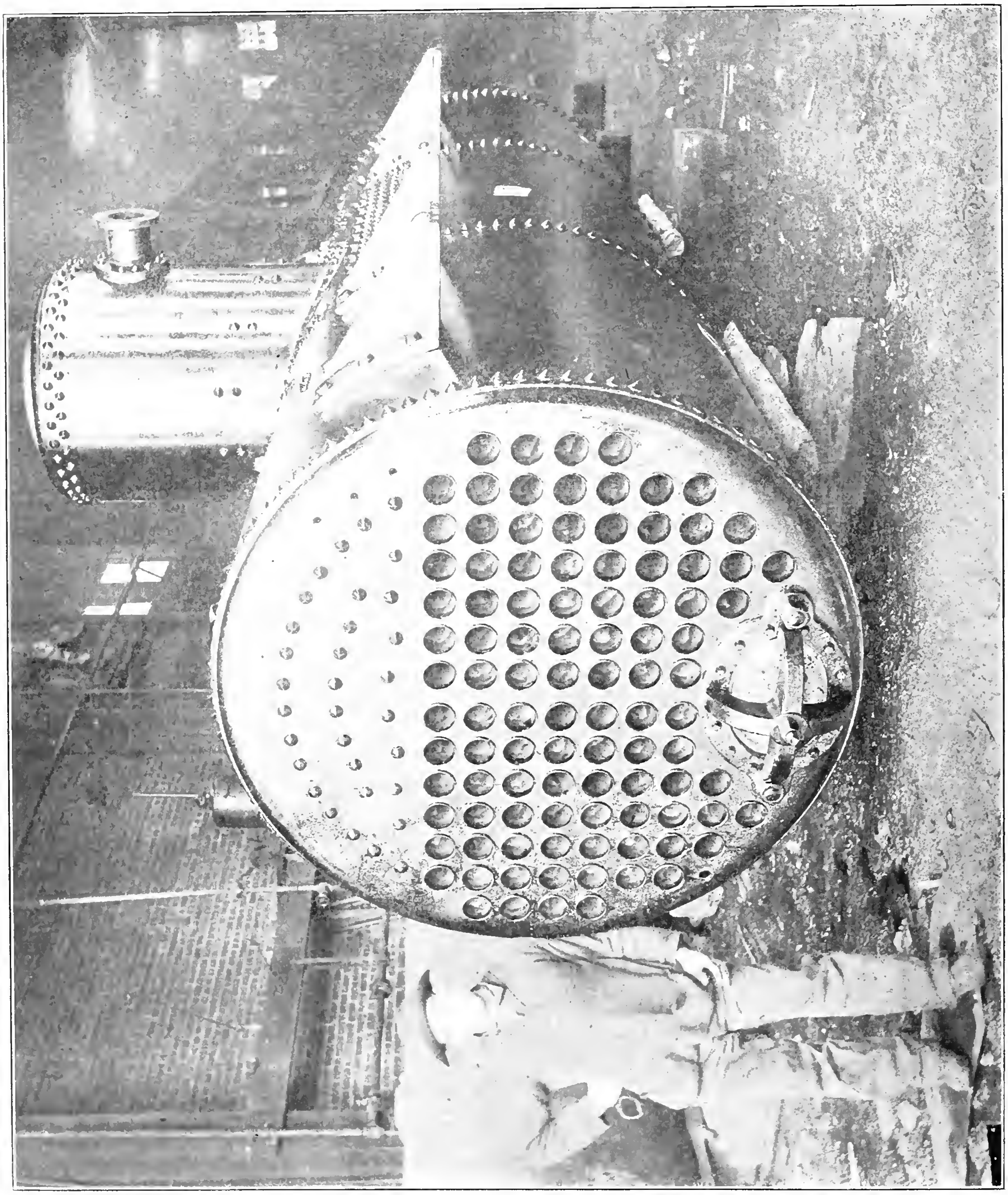


FIG. 37.

The sections *MKON*, *MKJH* and *GEJH* may be laid out in the same manner. Care should be taken to make the proper allowances in the length of the plates which form inside and outside rings. The laps must also be added to the pattern shown in Fig. 36.



A 72-INCH PLAIN TUBULAR BOILER FITTED WITH A STEAM DOME, LONGITUDINAL SEAMS JOINED WITH TRIPLE RIVETED BUTT STRAPS.

TRIANGULATION

In the preceding articles the methods used in laying out or expanding parallel and tapering forms were fully illustrated and described. The surfaces that the boiler maker encounters cannot always be expanded by the use of the two methods mentioned above. This is due to the fact that these surfaces do not conform to any particular law, that is, they are not cylindrical in form or conical, etc. Consequently some method must be devised whereby those forms can be laid out accurately and quickly. The method most commonly used is that of triangulation. Most young layersout seem to experience difficulty in grasping the principles involved in this method and in consequence are always experiencing difficulty in laying out forms by triangulation. This trouble is largely caused by the fact that the layerout has failed to grasp the elementary or underlying principles involved. We shall undertake to present these principles in such a manner that they will be readily understood. Once the boiler maker has these principles thoroughly mastered he should experience little or no difficulty in applying them to any problem that may arise in the practice of his profession.

The definition of the word triangulation is simply the measurement by triangles. In surveying, it is the series of triangles with which the face of a country is covered in a trigonometrical survey and the operation of measuring the elements necessary to determine the triangles into which the country to be surveyed is supposed to be divided. In boiler making, triangulation simply means the division of the surface of any irregular object into triangles, determining the lengths of their sides from the drawing and transforming them in regular order in the pattern. In constructing these triangles the lengths of three sides are known, and as it is obvious that from any three given dimensions only one triangle can be formed, this method furnishes an absolutely correct method of measurement. In all articles whose sides do not lie in a vertical plane, the length of a line running parallel with the form cannot be determined from the elevation above nor from the plan. The elevation gives us the distance from one end of the line vertically to the other as it appears

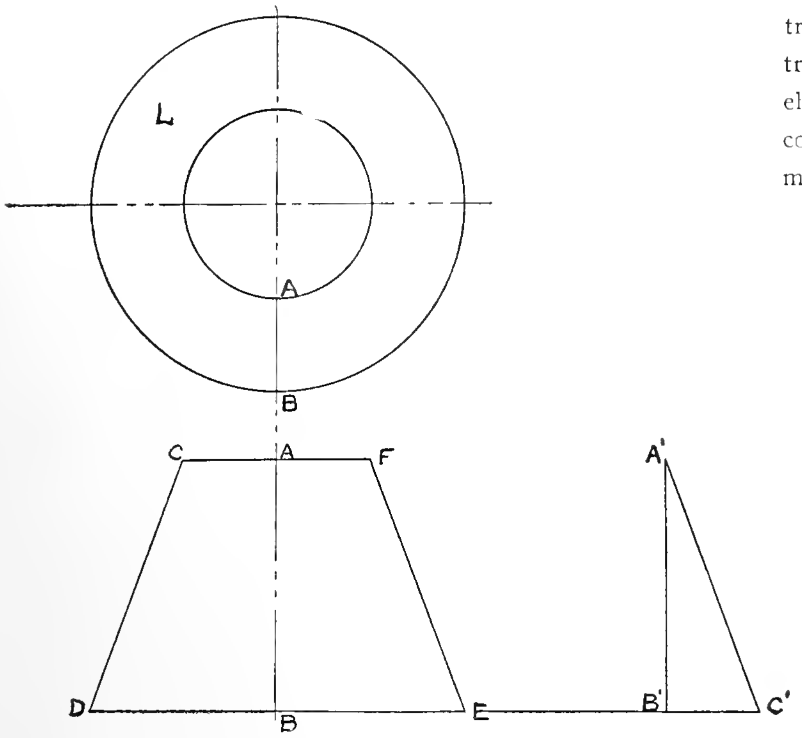


FIG. 1.

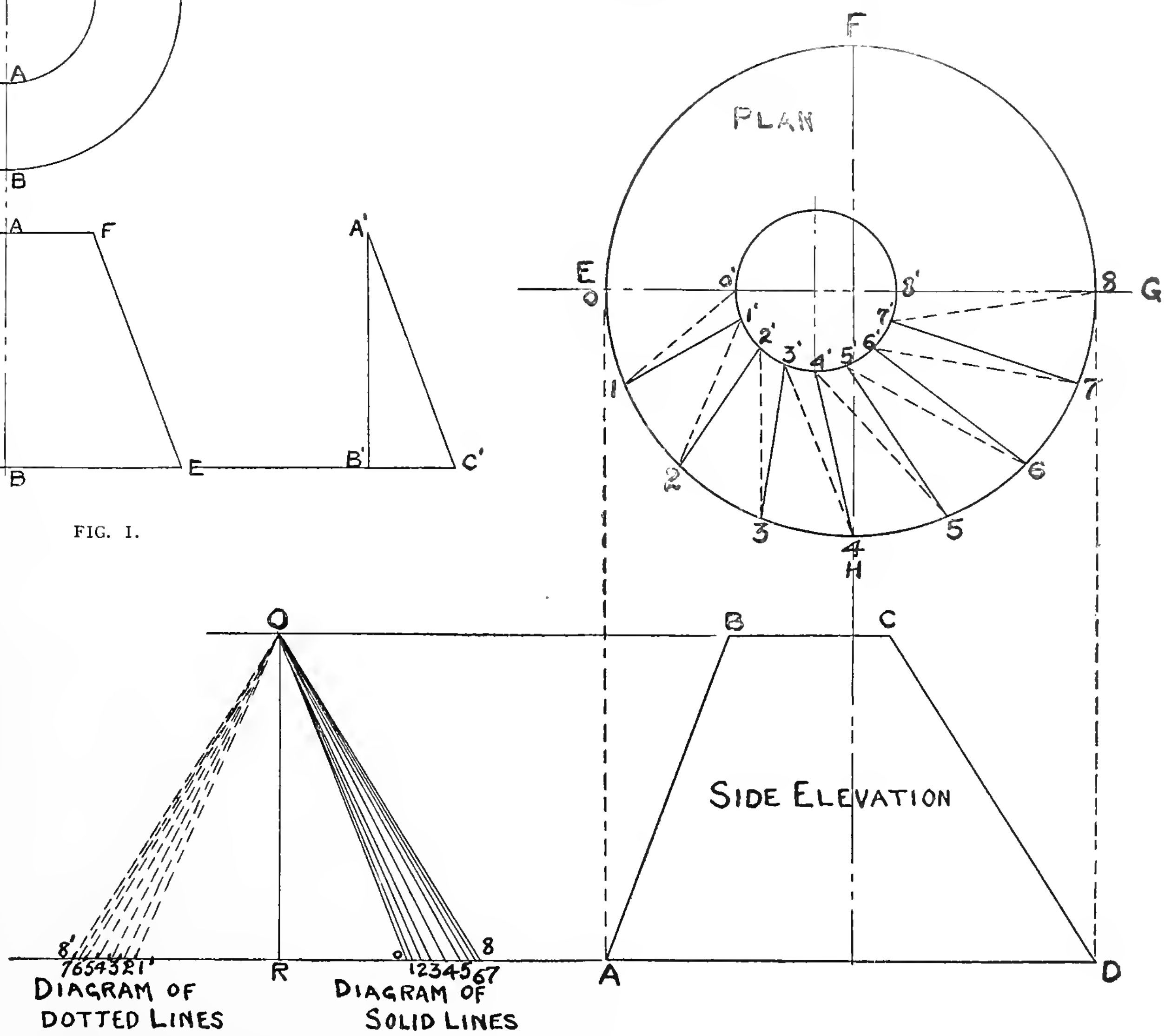


FIG. 2.

to the eye. To get the distance forward or back from one end of the line to the other we must go to the plan. From the foregoing we can readily see that the true length of a straight line lying in the surface of an irregular form can be found only by constructing a right-angled triangle whose base is the horizontal distance between the points and whose altitude is the vertical distance of one point above the other. The hypothenuse of this triangle is the true distance between the points, or the required length of the line. To illustrate this, let *C D E F,* Fig. 1, be the elevation of a conical article, and *L* its corresponding plan view. It is required to find the true length of the line *AB.* It is evident that the distance *AB* in the elevation, is the actual vertical height of the line, and that the distance *AB* in the plan is the actual horizontal length of the line. We will consequently proceed to construct a right-angle triangle whose height *A'B'* corresponds to the height *AB* in the elevation, and whose base *B'C* corresponds to the distance *AB* in the plan view. Draw *A'C'* and it is evident that the distance *A'C'* is the true length of the line *AB.* This is the principle upon which triangulation is based.

In Fig. 2, *A B C D* is the side elevation of a truncated scalene or oblique cone. We will assume that this truncated cone is a transition piece connecting two round pipes. It is also somewhat similar, though greatly exaggerated, to the throat sheet of a locomotive boiler. The idea of the article is simply to explain the method of triangulation, any other irregular piece would serve our purpose as well. *E F G H* is the corresponding plan view of the truncated cone. We will simply expand one-half of the article, the other half being the exact duplicate of it. Divide the large half circle *E H G* into any number of equal parts. Eight parts were taken in this case, though as a rule, the larger number of parts taken the more accurate will be the work. Divide the small semicircle into the same number of parts; number the divisions on the large semi-circle 0 to 8, and on the small semi-circle 0'-8'. Join the points 0-0', 1-1', 2-2', 3-3', etc., with full lines; also join the points 0'-1, 1'-2, 2'-3, 3'-4, etc., with dotted lines.

We are now ready to construct our triangles to find the true lengths of the lines 0-0', 1-1', etc., and the lines 0'-1, 1'-2, etc. Erect the vertical line *OR* and at right angles to *OR* draw a horizontal line. The line *OR* is equal to the vertical height from the line *BC* to the line *AD* or the actual vertical height of the cone. This line is evidently one leg of our triangles. The other legs are the distances 0-0', 1-1', 2-2', etc., as explained in Fig. 1. Transfer the distance 0-0' to *R*-0, the distance 1-1' to *R*-1, the distance 2-2', to *R*-2 on our diagram for triangles. Join *O*-0, *O*-1, *O*-2, *O*-3, etc., these lines give us the true lengths of the solid lines. In a similar way we find the true lengths of the dotted lines, laying the distances out to the left of *R* and joining these points with *O.* We now have the true lengths of all the solid and dotted lines and are ready to proceed with the actual expansion.

In Fig. 3 lay out the horizontal line 0-0' equal in length to the full line *O*-0 in Fig. 2. Set a pair of dividers to the spacing 0'-1', 1'-2', etc., on the small semi-circle and set another pair of dividers to suit the spacing of the large semi-circle. The setting of these dividers should be very carefully done as any little inaccuracy here will throw the whole work out. Now, with 0 as a center, with the dividers set to the large spacing, strike an arc. With 0' as a center, and the distance 0-1', Fig. 2, as a radius, strike an arc cutting the previous arc at 1. With 1 as a center, and the distance 0-1, Fig. 2, as a radius, strike an arc. Now, with 0' as a center, with the dividers set to the small spacing, strike an arc cutting the previous arc at 1'. Continue this operation until the points 8 and 8' are reached. Join the points 0, 1, 2, 3, 4, 5, 6, 7 and 8 with a

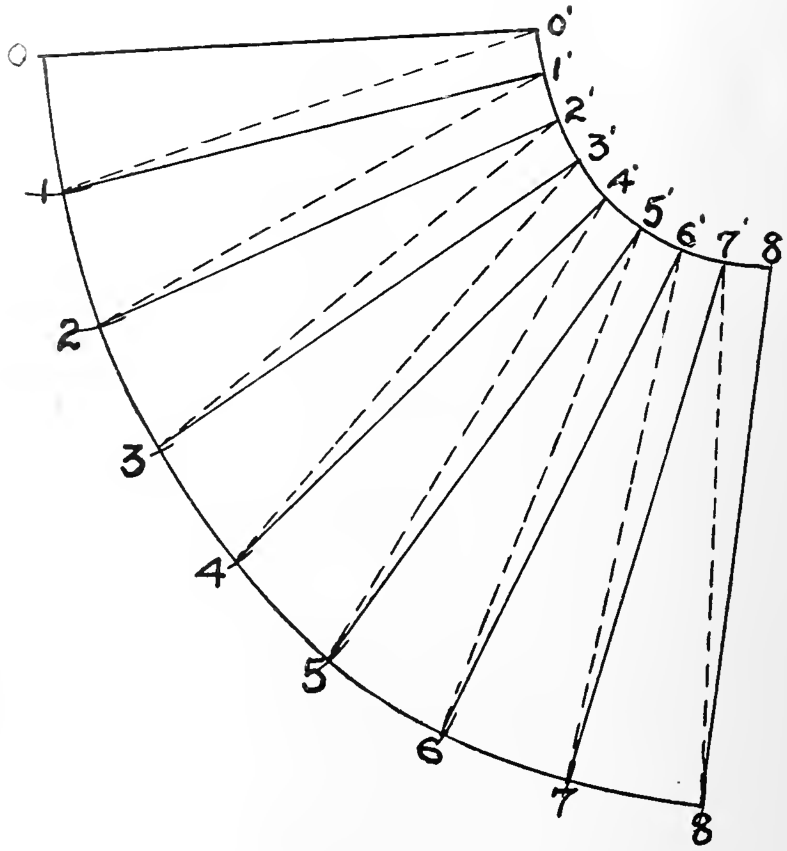


FIG. 3.

smooth curve, and similarly with the points 0', 1', 2', 3', 4', 5', 6', 7' and 8'. This then is the true expansion of half of the truncated cone shown in Fig. 2.

The above illustrates in a simple manner the method of developing irregular surfaces by triangulation. It will be readily seen that it is not an absolutely accurate method of laying out, due to the fact that a curved surface is divided into a small number of parts and these parts are assumed to be straight lines. However, with a sufficient sub-division and with great care on the part of the layerout, no great inaccuracy will result. It is not advisable to lay out surfaces by triangulation, except as a source of last resort, that is, if there is any other feasible method for expanding the article, use it. However, there are a great many irregular-shaped forms that can only be expanded by adopting this method, and every layerout should understand it thoroughly. The frustrum of an oblique cone, which we have just expanded, can be laid out by applying the principles of laying out tapering forms. It was chosen as an easy example, illustrating the fundamental principles of triangulation. In a later chapter we will apply the principles of triangulation to more intricate forms.

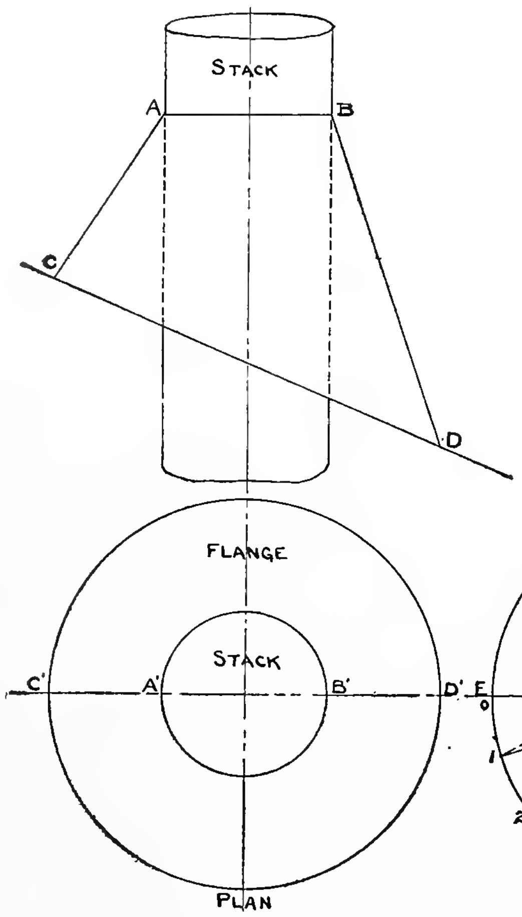
LAYING OUT A CIRCULAR HOOD FOR A SMOKESTACK.

In this article we will consider the development by triangulation of a circular hood for a stack which projects through an inclined roof. In Fig. 4 is shown the elevation of the stack; *ABCD* is the elevation of the circular hood. *A'B'* is the plan view of the stack and the circle *C'D'* the plan view of the outer edge of the flange. This shows as a circle in the plan view, as it is required that the flange be equal on all sides.

Fig. 6 shows an elevation *ABCD* of the hood similar to *ABCD,* Fig. 4. Above this elevation is a half plan of the top *AEB*. This half plan is divided into ten equal parts. From the points on the larger semi-circle *EHG* from o to 10. Connect the points 0-0', 1-1', 2-2', 3-3', etc., with full lines, and the points 0'-1, 1'-2, 2'-3, 3'-4, etc., with dotted lines. These solid and dotted lines form the bases of a series of right-angled triangles, whose altitudes are obtained from the elevation, Fig. 6. The hypothenuse of these triangles will give us the correct lengths of the lines on the pattern.

Returning to Fig. 6, connect the points on *AB* with the correspondingly numbered points on the line *CD*. Also extend the lines *AB* and *DS* indefinitely to the right. Do the same with the points on the line *CD*. At *S* erect a perpendicular line between the lines *BR* and *DS*. At *S* set off the

ELEVATION



PLAN
FIG. 4.

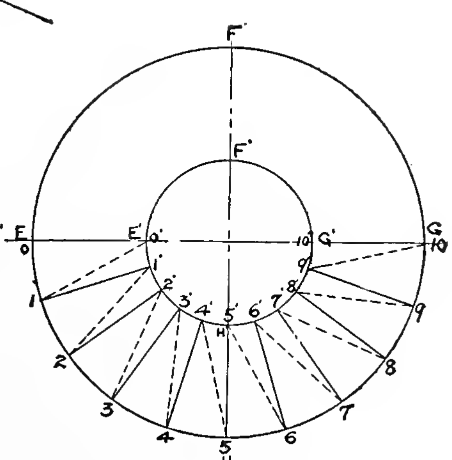


FIG. 5.

these points drop perpendiculars to *AB*. We must now obtain the actual shape of the section as it passes through the roof. To do this, construct the half plan of the base *GHK* and divide this semi-circle into the same number of equal parts as the semi-circle *AEB*. From these points erect perpendiculars cutting the line *GK*. Extend these lines to cut the line *CD*. From these points drop lines perpendicular to *CD*. On these lines lay out distances equal to the similarly numbered perpendicular lines on the half plan view *GHK*. Through these points draw a smooth curve. This gives us the true shape of the section as it passes through the roof and furnishes us with the stretchout of the base used in obtaining the pattern.

We are now ready to prepare for constructing the triangles for developing the pattern. In Fig. 5 construct a plan view of the hood similar to that shown in Fig. 4. Divide these semi-circles similarly to the semi-circles in Fig. 6 and number the points on the smaller semi-circle, *E'H'G'*, from 0' to 10' and distance *SQ* equal to the distances 0'-1, 1'-2, 2'-3, etc., Fig. 5. At *Q* erect a perpendicular cutting the line *BR* at *P*. Join *P* with the points, 0, 1, 2, 3, etc., on the line *RS*. This gives us the true lengths of the dotted lines on the pattern. Now at *O* on line *DS* erect a perpendicular line cutting the line *BR* at *N*. Now set off the distance *OM* equal to the lengths of the full lines in Fig. 5, 0-0', 1-1', 2-2', etc., which are all equal. Erect the perpendicular *ML* and join *L* with the various points on the line *NO*. This gives us the lengths of the solid lines on the pattern.

We are now ready to lay out our pattern. The stretchout of top end of the flange is obtained from the semi-circle *AEB,* Fig. 6, and that of the lower part, or where the flange strikes the roof, is obtained from the section *CFD*, Fig. 6. Draw the line *A'C'*, Fig. 9, equal in length to *AC*, Fig. 6. Set a pair of dividers to the distance 0-1 on *CFD* and another pair to the distances 0'-1', 1'-2', etc., on *AED*. These distances are all equal. With 0 as a center and 0-1 on *CFD* as a

radius strike the arc o-1. With o′ as a center and the distance *P*-1, Fig. 8, as a radius, strike an arc cutting the previously constructed arc at 1. With 1 as a center and the distance *L*-1, Fig. 7, as a radius, strike an arc, and with o′ as a center and

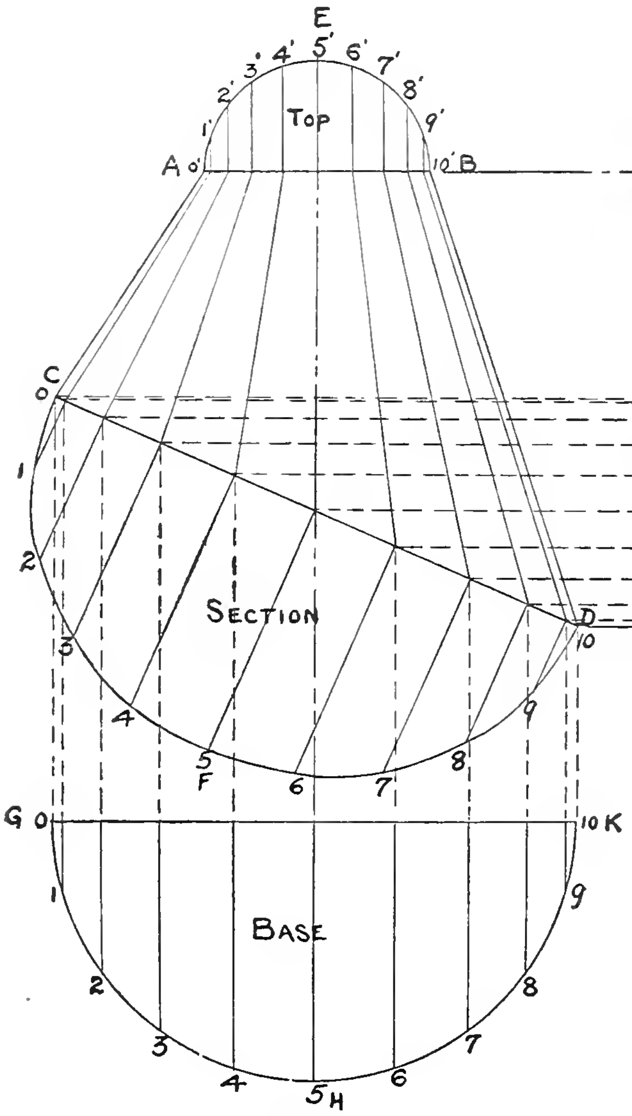


Fig. 6.

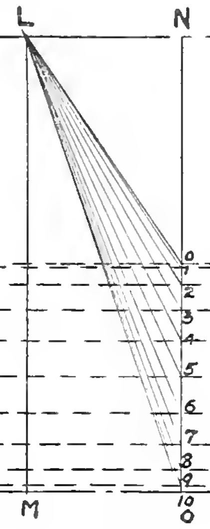


Fig. 7
Diagram Solid Lines

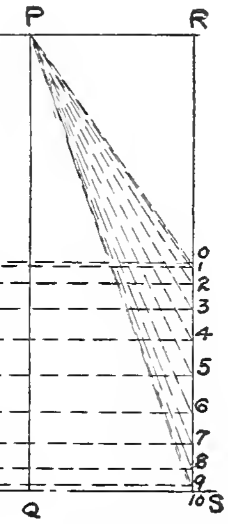


Fig. 8
Diagram Dotted Lines

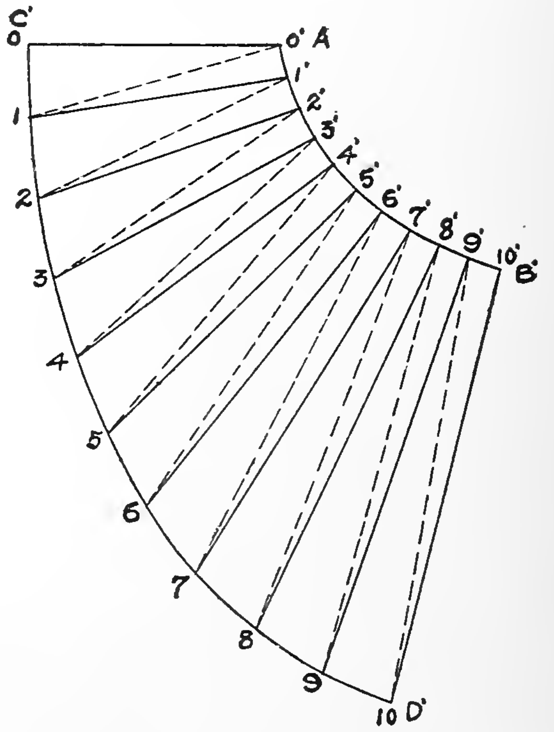


Fig. 9.

the distance o′-1′, Fig. 6, as a radius, strike an arc cutting this arc at 1′. Continue this process until the points 10 and 10′ are reached. Draw a smooth curve through these points and join 10 and 10′. The resulting surface *A′B′C′D′* gives us the development of one half of the hood. The other half is exactly similar.

THE LAYOUT OF A "Y" CONNECTION.

The plan and elevation of a "Y" connection, such as it is frequently necessary to construct for the uptakes of boilers or in branch pipe work, is shown in Fig. 10. The main pipe is circular and the two branch pipes are oval in shape, the diameter of the large pipe and major diameter of the small pipes being the same. It will be seen that not only would the connection from the large pipe to one of the smaller ones be an irregular and difficult piece to lay out, but that the interesection of two of these irregular pieces make the problem still more complicated. The fact that the connections to each of the branch pipes are exactly similar brings their intersection in a vertical plane, as shown by the line *A*4. Divide the half plans of the large pipe and one of the small pipes into the same number of equal spaces. Number the points on the large pipe 1, 2, 3, 4, 5, 6 and 7, and on the small pipe 8, 9, 10, 11, 12, 13 and 14. Now divide the surface of the connection into triangles by connecting points 1-8, 2-9, 3-10, etc., by solid lines and the points 2-8, 3-9, 4-10, etc., by dotted lines, as shown in Fig. 10.

It is necessary to find the true length of each of these lines of which we have just drawn the plan and elevation, in order to obtain the shape of the connection when stretched out flat.

Draw the line *BA*, Fig. 11, and at any point, as *Y*, square up the line *XY*. It will be seen from the elevation, Fig. 10, that the vertical distance between the upper and lower ends of each of the lines of which we wish to get the true length is the same; that is, it is the perpendicular distance between the lines 1-7 and 8-14. Therefore, lay off this distance in Fig. 11 from *Y* to *X* and then set the trams to the distance 1-8 in the

plan, Fig. 10, with *Y* as a center, Fig. 11, lay off the distance *Y*8 to the right of the line *YX*. Again, set the trams to the distance 2-8 in the plan, Fig. 10, and with *Y* as a center lay off the distance *Y*8, Fig. 11, to the left of the line *XY*. Draw the solid line *X*8, and also the dotted line, *X*8. These lines will then be on the half plan of the branch pipe), strike an arc intersecting the arc previously drawn at point 13. Again set the trams to the solid line **X**-13, Fig. 11, and with 13, Fig. 12, as a center, strike an arc at point 6. With 7 as a center and with dividers set to the distance 7-6, Fig. 10 (the length of the equal spaces

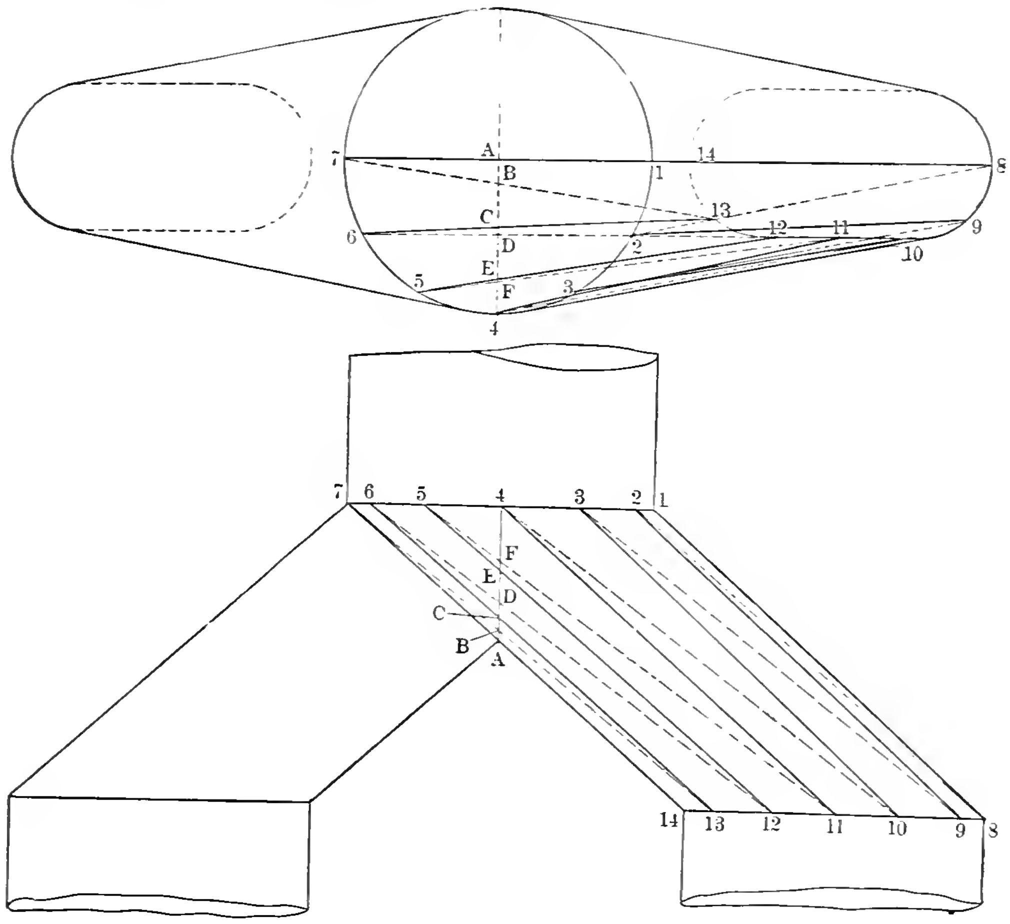


FIG. 10.

the true lengths of the solid line 1-8 and the dotted line 2-8, shown in Fig. 10.

Perform the same operation for each of the solid and dotted lines in Fig. 10, obtaining the lines *X*9, *X*10, *X*12, *X*13 and *X*14, Fig. 11. In order to avoid confusing the figure, since all of the lines are of nearly the same length, draw the solid lines at the right of the figure, and the dotted lines at the left.

in the half plan of the large pipe), strike an arc intersecting the arc previously drawn at point 6. Proceed in a similar manner, locating the points 5, 4, 3, 2 and 1 on the long edge of the sheet, and the points 12, 11, 10, 9 and 8 on the short edge of the sheet.

Having obtained the pattern for the entire connection from the large pipe to one of the small ones, it is now an easy mat-

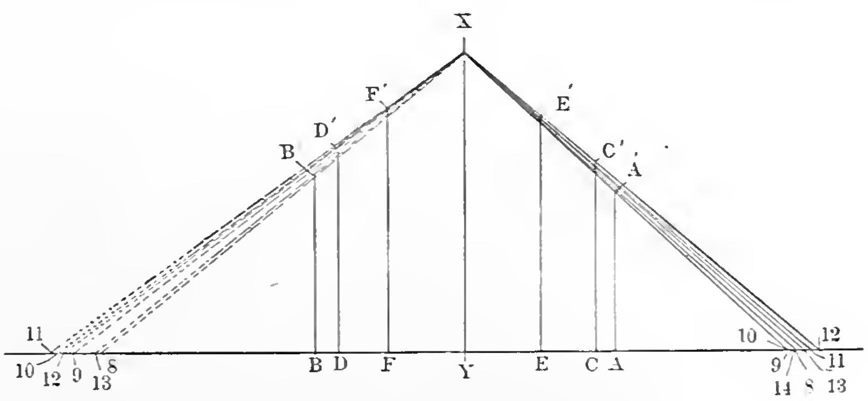


FIG. 11.

Having obtained the true length of all the lines which form the triangles into which the connection is divided, we are now ready to lay out the sheet as it will be before it is rolled up. Draw the line 7-14, Fig. 12, equal in length to the line 7-14, shown in the elevation, Fig. 10. Now set the trams to the dotted line *X*-13, Fig. 11, and with 7, Fig. 12, as a center draw an arc at the point 13. With 14 as a center and the dividers set to the distance 14-13 (the length of one of the equal spaces

ter to locate the line of intersection between the two intersecting connections. Set the trams to the distance 7*B* in the plan, Fig. 10 and with *Y*, Fig. 11, as a center lay off the distance *YB*. At the point *B* square up the line *B B′* until it intersects the line *X*13: then set the trams to the distance *X B′* and with the point 7, Fig. 12, as a center, lay off the distance 7*B* along the line 7-13. Again set the trams to the distance 6*C* on the plan, Fig. 10, and with *Y*, Fig. 11, as a center lay off the distance

$Y\,C$; at C square up the line $C\,C'$ until it intersects the line $X13$ at the point C'; then set the trams to the distance $X\,C'$; and with point 6, Fig. 12, as a center lay off the distance $6C$ along the line 6-13. In a similar manner locate the point D on the line 6-12; E on the line 5-12, and F on the line 5-11. Draw a smooth curve through these points, and then the figure A, 4, 1, 8, 14 represents a half pattern of the connecting pipe.

This problem shows how the principles of triangulation make possible the solution of problems which require the development of surfaces of which there is no regular form or taper. The only inaccuracies or errors which creep into this, as well as any other problem which is solved by triangulation, are those due to the fact that the lines forming the triangles into which the surfaces are divided are considered as straight lines when, as a matter of fact, they are slightly curved. Unless there is a very great curvature to the surface, however, this error is very small and the patterns developed by this method will be found to fit nicely into the required positions.

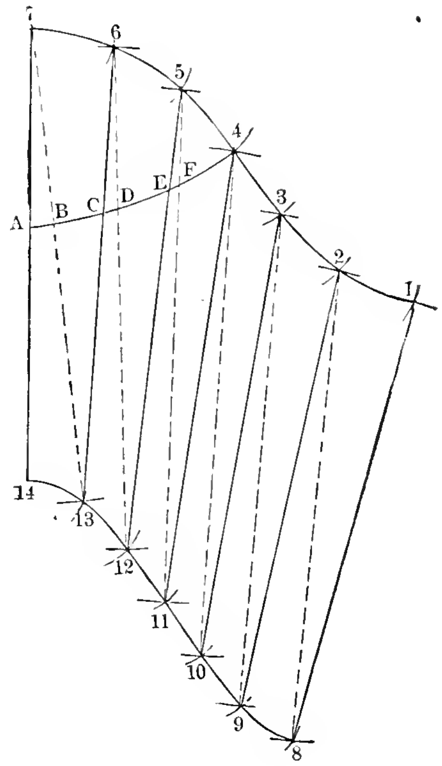


FIG. 12.

HOW TO LAY OUT A TUBULAR BOILER.

In this layout of an ordinary tubular boiler, one which is generally rated as an 80-H. P. boiler has been selected, as being a standard size. It is 60 inches in diameter by 14 feet long. It is desired to give as complete a description as possible of the design and layout of this boiler, using several different formulæ to show how each point is found. The object of this is to give some idea of the necessity of having all boilers constructed under some law or authority. Under present conditions boilers can be constructed from mere ideas, and this results in some parts of the boiler being unnecessarily strong, while other parts are too weak. Many of the mysterious boiler explosions result from this class of construction.

In computing the allowable working pressure of the boiler, we will first have to find out what pressure is required to suit the needs of the particular plant where the boiler is to be installed. Let us assume that our customer has placed an order with us for a boiler to be constructed for a working pressure of 150 pounds per square inch, but expressly states that at times he will need a pressure of 175 pounds per square inch. He figures that in time he may need this additional 25 pounds pressure, so he orders his boiler accordingly. The object in bringing this out is to show purchasers of boilers that it is a wise idea when installing new boilers to have them constructed for a greater pressure than they need at the time of purchasing, as there is always a tendency to use more pressure rather than less. It is not to be expected that the majority of plant owners know how to figure out whether these boilers are safe for the pressure they are carrying. Consequently, advantage is taken of their ignorance in this respect. Instances are known where it was desired to increase the pressure of a boiler, and a boiler maker was called in to see if the boiler could stand an increased pressure. After he had made a general survey, or bird's-eye view of the boiler, he advised the owners that it would be safe to do so, and they acted accordingly. The majority of parties who authorize this increased pressure do not know one item about figuring out the safe working pressure of a boiler.

An idea seems to prevail that the more rivets there are in a seam the stronger the joint will be. We will see how this works out in specific cases a little further along. Another feature to be considered is the factor of safety. Some use 4, others 5. A set factor is all right providing it specifies in detail how the work is to be done using that factor, but the grade of work should be taken into consideration in deciding the factor. Therefore, to encourage good work we should have different percentages, that we can add, covering each operation where work may be slighted. The very best of construction consists of drilling all holes and having longitudinal seams made with double-butt strapped joints. If the holes are not drilled in place, the next best construction is punching the holes small and reaming out from 1/8 inch to 3/16 inch after the sheets are in place.

How to Ascertain the Factor of Safety.

When cylindrical shells of boilers are made of the best material (either iron or steel), with all holes drilled in place, the plates afterwards taken apart and the burrs removed. and all longitudinal seams fitted with double-butt straps, each at least (5/8) five-eighths the thickness of the plates they cover, the seams being double riveted, with rivets 75 percent over single shear and having the circumferential seams constructed so the percentage is at least one-half that of the longitudinal seams, and provided that the boiler has been open for inspection to the government inspector during the whole period of construction; then 4 may be used as a factor of safety. But when the above conditions have not been complied with, the conditions in the following scale must be added to the factor 4, according to the circumstances of each case:

A = .1—To be added when all holes are fair and good in longitudinal seams, but drilled out of place after bending.

B = .2—To be added when all holes are fair in longitudinal seams, but drilled before bending.

C = .2—To be added when all holes are fair and good in longitudinal seams, but punched after bending.

D = .3—To be added when all holes are fair and good in longitudinal seams, but punched before bending.

*E = .7—To be added when all holes are not fair and good in longitudinal seams.

F = .07—To be added if the holes are all fair and good in the circumferential seams, but drilled out of place after bending.

G = .1—To be added if all holes are all fair and good in the circumferential seams, but drilled before bending.

H = .1—To be added if the holes are all fair and good in the circumferential seams, but punched after bending.

I = .15—To be added if the holes are all fair and good in the circumferential seams, but punched before bending.

*J = .15—To be added if the holes are not fair and good in the circumferential seams.

K = .2—To be added if double butt straps are not fitted to the longitudinal seams, and said seams are lap and double riveted.

L = .07—To be added if double butt straps are not fitted to the longitudinal seams, and said seams are lap and treble riveted.

M = .3—To be added if only single butt straps are fitted to the longitudinal seams, and said seams are double riveted.

N = .15—To be added if only single butt straps are fitted to the longitudinal seams, and said seams are treble riveted.

O = 1.—To be added when any description of joint in the longitudinal seam is single riveted.

P = .2—To be added if all holes are punched small and reamed afterwards, or drilled out in place.

Q = .4—To be added if the longitudinal seams are not properly crossed.

*R = .4—To be added when material or workmanship is in any way doubtful, and the inspector is not satisfied that it is of best quality.

S = 1.—To be added if boiler has not been open for inspection during the whole period of construction.

Note.—When marked with an (*) the factor may be increased still further if the workmanship or material is such as in the inspector's judgment renders such increase necessary.

Note.—Steam Boiler Inspection Act, 1901, for British Columbia, Canada.

The following examples will serve to show how the factor may be determined for any given case:

Lap, treble riveted, holes punched full size before bending:

$$\begin{array}{l} 4.00 \\ .30 = D \\ .15 = I \\ .07 = L \\ \hline 4.52 = \text{Combined factor.} \end{array}$$

To this is every possible chance of having to add $E = .7$ and $J = .15$, this then would make the factor 5.37.

Lap, treble riveted, holes punched small, being drilled or reamed out in place:

$$\begin{array}{l} 4.00 \\ .20 = P \\ .07 = L \\ \hline 4.27 = \text{Combined factor.} \end{array}$$

In this method we are able to drop both D and I and bring in P, making a difference of .25 in percentages. It also cuts out any chance of E or J being added in, and it is the best method that can be exercised with a lap treble riveted joint, having holes punched before bending. From ⅛ inch to 3/16 inch should be drilled out of each hole.

Treble-riveted butt joint, with holes punched full size:

$$\begin{array}{l} 4.00 \\ .30 = D \\ .15 = I \\ \hline 4.45 = \text{Combined factor.} \end{array}$$

To this there is every possible chance of having to add $E = .7$ and $J = .15$. This would then make the factor 5.30.

Treble-riveted butt joint, with holes punched small, being drilled or reamed out in place:

$$\begin{array}{l} 4.00 \\ .20 = P \\ \hline 4.20 = \text{Combined factor.} \end{array}$$

In this method we are able to drop both D and I and bring in P, making a difference of .25 in percentage. It also cuts out any chance of E or J being added in, and it is the best method that can be exercised other than holes drilled in place. The reaming should be not less than ⅛ inch in diameter.

It will be noted that with holes drilled in place we can use a factor 4, providing we have double butt straps at the longitudinal seams, but with the same joint with holes punched small and reamed out, the combined factor is 4.27. The latter will be generally used on account of the punching being so much cheaper, even though heavier plates might be required.

In order to calculate the allowable working pressure of a boiler it is necessary to know not only the factor of safety but also the efficiency of the riveted joints, since a riveted joint is always weaker than a solid plate, and therefore the pressure allowed a boiler must be less than would be the case if the shell were one solid plate with no joints. The efficiency of the joint is the ratio of the strength of the joint to the strength of the solid plate. The strength of the net section of the plate after the rivet holes are cut out is figured, and also the shearing strength of the rivets is figured. Then the smaller of these values is used as the strength of the joint to be used in the ratio. Different laws have given various formulæ of slightly different form for figuring the efficiency of a joint, as will be seen from the examples given below. These do not give exactly the same results, as different conditions and assumptions were used in deducing them.

According to the practice of the Hartford Steam Boiler Inspection & Insurance Company, the efficiency of a riveted joint would be found as follows:

Treble Riveted Lap Joint.

Steel plate, tensile strength per square inch of section 60,000 pounds.

Thickness of plate, 7/16 = .4375

Diameter rivet holes, 15/16 = .9375

Area of one rivet hole = .69029

Pitch of rivets, 3 15/16 = 3.9375

Shearing resistance of steel rivets per square inch 42,000 pounds.

$3.9375 \times .4375 \times 60000 = 103{,}359$ pounds = strength of solid plate,

$$3.9375 - .9375 = 3.00.$$

$3 \times .4375 \times 60000 = 78{,}750$ pounds, strength of net section of plate.

$3 \times .69029 \times 42000 = 86{,}976.54$ pounds, strength of three rivets in single shear,

$$100 \times 78750 \div 103{,}359 = 76 \text{ percent}$$

efficiency of joint. See Fig. 1.

The British Columbia formula gives the following results:

P = Pitch of rivets in inches.
D = Diameter of rivets in inches.
A = Area of one rivet in square inches.
N = Number of rivets in one pitch (greatest pitch).
Y = 23 for steel rivets and plate.
Y' = 28 for steel rivets and plate.
T = Thickness of plate in inches.
C = 1 for lap.

$C = 1.75$ for double butt strap joint.

$F =$ Factor of safety.

$\% =$ Percentage of plate between greatest pitch of rivets.

$\%^1 =$ Percentage of rivet section as compared with solid plate.

$$\frac{100 \times (P - D)}{P} = \% \text{ for iron or steel plates.}$$

$$\frac{(\text{Pitch} - \text{diameter of rivet hole}) \times 100}{\text{Pitch}} = \% \text{ of strength of plate, at joint, compared with solid plate.}$$

$$\frac{(\text{Area of rivets} \times \text{number rows of rivets}) \times 100}{\text{Pitch} \times \text{thickness of plate}} =$$

% of strength of rivets as compared with solid plate.

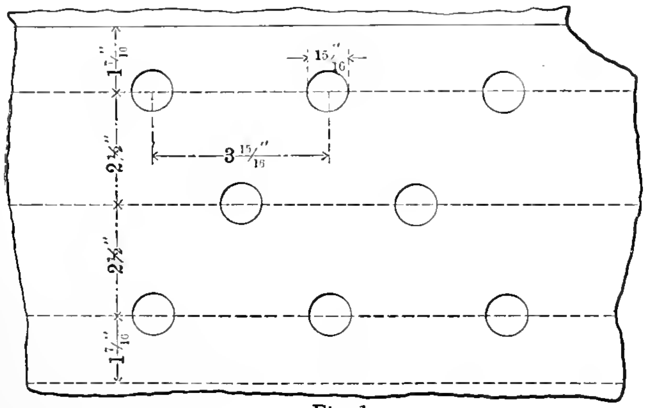


Fig. 1

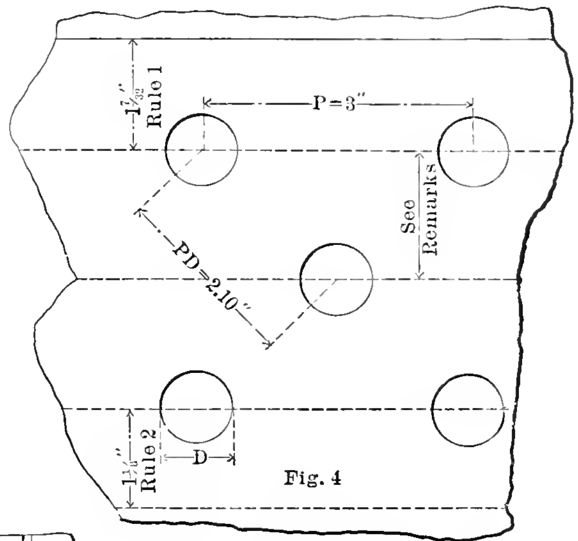


Fig. 4

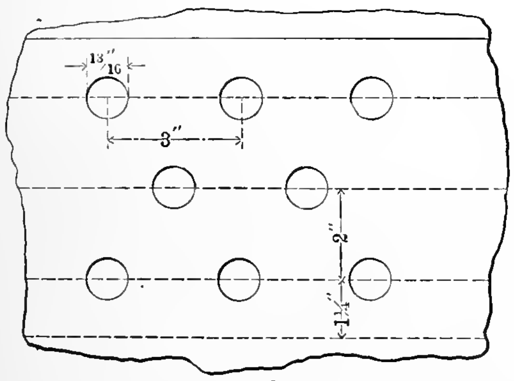
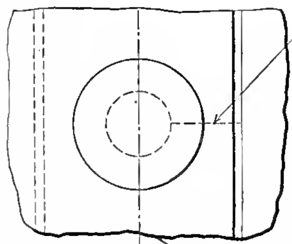


Fig. 2


Plan (Fig. 5)

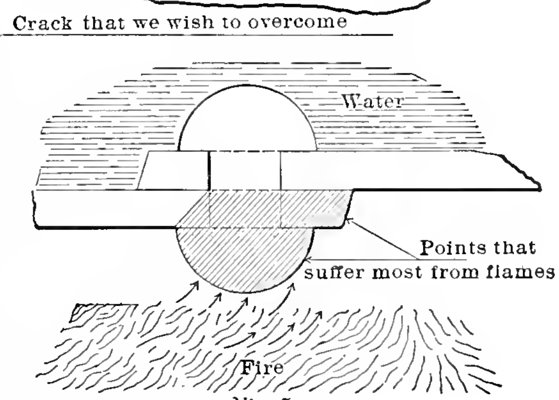


Fig. 5

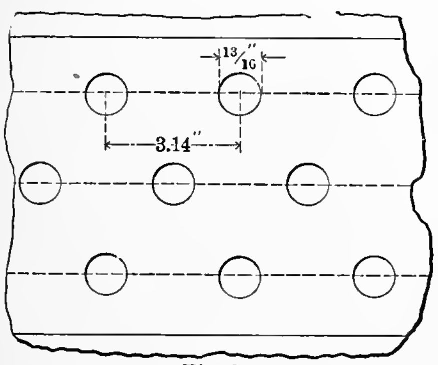
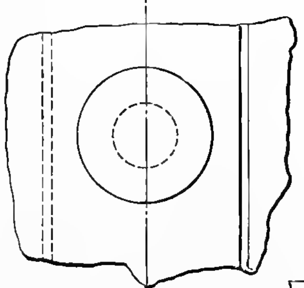


Fig. 3


Plan (Fig. 6)

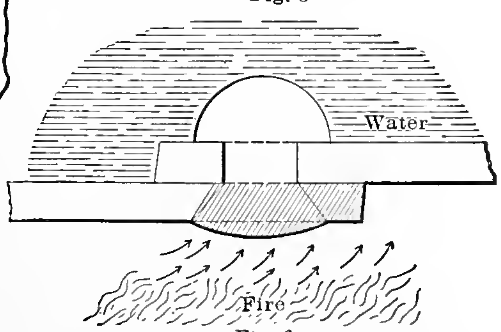


Fig. 6

$$\frac{100 \times A \times N \times Y \times C \times F}{4 \times Y' \times T \times P} = \%' \text{ for steel plates rivets.}$$

$100\ (P - D) = (3.9375 - .9375)\ 100 = 3 \times 100 = 300.$

$300 \div 3.9375 = 76\ \%$ net section plate between rivets.

$$\frac{100 \times .69029 \times 3 \times 23 \times 4.20}{4 \times 28 \times 3.9375 \times .4375} = 104\% = \text{percentage of strength of rivets compared to plate.}$$

NOTE.—*F* in this example is factor on longitudinal seam only.

The computation, according to the Canadian marine law, is given below:

Taking the same example, when we obtain 104 percent with B. C. formula, we find as follows:

$$\frac{.69029 \times 3 \times 100}{3.9375 \times .4375} = 120 \text{ percent.}$$

NOTE.—It will be noticed that the Canadian marine law does not take into consideration the factor of safety as is done in the British Columbia law. Also in the formula for the percentage of strength of the rivets as compared with the solid plate, no account is taken of the fact that the shearing strength of the rivets is different from the tensile strength of the plate. Assuming that the shearing strength of the rivets is 42,000 pounds

per square inch, and the tensile strength of the plate 60,000 pounds per square inch, then the percentage strength of the rivets, compared to the solid plate, is 84 instead of 120, as given by the formula. In the British Columbia law this has been taken care of by the constant factors in the formula. Thus our percentage with 7/16 plate, treble-riveted lap joint 7/8 rivets, 15/16 holes is 76 percent in each instance, as the net section of the plate was found to be weaker than the strength of the rivets.

To get the allowable working pressure for a given thickness of plate for this joint we figure as follows:

$$\frac{T\,S \times R \times 2T}{D \times F} = B$$

TS = Tensile strength.
T = Thickness.
D = Inside diameter of boiler.
F = Factor of safety.
R = Percentage of joint.
B = Working pressure per square inch.

$$\frac{60000 \times .76 \times .873}{60 \times 4.27} = \frac{665.0}{4.27} = 156$$ pounds allowed with holes punched small and reamed out in place.

$$\frac{60000 \times .76 \times .875}{60 \times 4.52} = \frac{16,625}{1.13} = 147$$ pounds allowed with holes punched full size before bending. All holes being perfectly fair.

$$\frac{60000 \times .76 \times .875}{60 \times 4.07} = 163$$ pounds allowed with all holes drilled in place.

NOTE.—F is the combined factor in these examples.

Just to give some idea of the pressure allowed on the same boiler, with the same joint and pitch of rivets, but having the holes punched full size and more or less of them in the circumferential and longitudinal seams, not fair or good, the following is given: As the extent to which they are blind, will have the effect of deciding just what should be added to the factor, this is left to the inspector. The British Columbia laws would bring the factor up to 5.37, or even greater, if the inspector considered the work such as to warrant it. Assuming 5.37 as a factor we figure as follows:

$$\frac{60000 \times .76 \times .875}{60 \times 5.37} = 124 \text{ pounds.}$$

Thus we see just what effect the workmanship has on the factor and amount of pressure that can be allowed. It is possible with a treble-riveted lap joint to get 76 percent efficiency and build boilers good for 163 pounds pressure. Yet another boiler constructed with the defects which have been pointed out will, when completed, look as well and get just as high a pressure. Thus we see the great importance of government inspection and laws covering construction of boilers. Let us also figure this same style of joint with 3/4 rivets instead of 7/8, and we will see what effect it has in the efficiency of the joint.

Treble-Riveted Lap Joint.

Steel plate, tensile strength per square inch of section, 60,000 pounds.

Thickness of plate, 7/16 = .4375
Diameter rivet hole, 13/16 = .8125
Area of one rivet hole = .5185
Pitch of rivets = 3 inches.

Shearing resistance of steel rivets per square inch = 42,000 pounds.

3 × .4375 × 60,000 = 78,750 pounds, strength of solid plate.

(3 — .8125) × .4375 × 60,000 = 57,421.875 pounds, strength of net section of plate.

.5185 × 3 × 42,000 = 65,331 pounds, strength of 3 rivets in single shear.

57,421.875 ÷ 78,750 = 73 percent, efficiency of joint. See Fig. 2.

It might be asked how the pitch of rivets is decided. No set pitches can be stated for every joint, but a maximum pitch can be stated. While it is true the greater the pitch the greater will be the percentage of the net section of plate, but at the same time the percentage strength of the rivets, compared to the solid plate, is decreasing. It is this weakness that makes the single and double-riveted lap joint longitudinal seams low in efficiency, and makes them unsuitable for boilers of large diameters and pressure. It will be seen the efficiency of a joint with 3/4 rivets, 3-inch pitch is 3 percent weaker than a joint with 7/8 rivets, 3 15/16-inch pitch.

By the Canadian marine law and British Columbia formula the pitch may be ascertained as follows:

$$(C \times T) + 1\tfrac{5}{8} = PM$$

T = Thickness of plates in inches.
PM = Maximum pitch of rivets in inches not to exceed 10 inches.
C = Constant applicable from the following table::

No. of Rivets in One Pitch.	Constant for Lap Joint.	Constant for Double Butt Strap Joint.
One	1.31	1.75
Two	2.62	3.50
Three	3.47	4.63
Four	4.14	5.25
Five		6.00

For a treble-riveted lap joint with 7/16-inch plate, 3/4-inch rivets, and 13/16-inch rivet holes, the pitch will be found as follows:

(3.47 × .4375) + 1.625 = 1.518 + 1.625 = 3.143-inch pitch.

Therefore, the percentage of the net section of the plate to the solid plate will be

$$\frac{100 \times (3.143 - .8125)}{3.143} = 74 \text{ percent.}$$

NOTE.—See Fig. 3.

It will be seen with these formulæ we do not get the same percentage in net section with 3/4 rivets as we did with 7/8 rivets. The maximum pitch, 3.14 inches, was used. If we use 3-inch pitch, as was done with the preceding example, the percentage of the net section of the plate will be a fraction less, but the percentage of the rivet area will be greater.

It might be asked whether it is possible to design a seam for a double-riveted lap joint, with any size rivets, that will permit the same working pressure as in the preceding problems. Let us see if this is possible. First, we know our rivet area will be less, so we will use a larger rivet, with a view of getting the necessary rivet area. We will use a 15/16 rivet in our example.

Steel plate, tensile strength per square inch of section, 60,000 pounds.

Thickness of plate, 7/16 = .4375

Diameter of rivet holes = 1 inch.

Area of rivet holes = .7854

Pitch of rivets, 3 5/16 = 3.3124

Shearing resistance of steel rivets per square inch, 42,000.

3.3124 × .4375 × 60,000 = 86,887 pounds, strength of solid plate.

3.3124 — 1 = 2.3124

2.3124 × .4375 × 60,000 = 60,700 pounds, strength net section of plate.

.7854 × 2 × 42,000 = 65,973.6 pounds, strength of two rivets in single shear.

60,700 ÷ 86,887 = 70 percent efficiency.

Assume that the holes are punched small, as in the treble-riveted lap joint, and see just what pressure we can allow.

$$\begin{array}{l} 4.00 \\ .20 = P. \\ .20 = K. \\ \hline 4.40 = \text{Combined factor of safety.} \end{array}$$

$$\frac{60000 \times 7 \times .875}{60 \times 4.40} = 139 \text{ pounds allowable working pressure.}$$

156 pounds treble-riveted lap joint, with 7/8-inch rivets.
139 pounds double-riveted lap joint, with 15/16-inch rivets.

17 pounds difference under same conditions.

Thus we see what efficiency and allowable pressure can be obtained with a treble-riveted lap joint, and also the decrease in these which will occur in a boiler with only a double-riveted lap joint. We also ascertain how important it is for the factor of safety to be set according to the actual conditions of holes, etc. We further see the value of all holes being reamed, so that the factor of safety is not allowed to increase. A high factor is not necessary with good work.

A question most liable to be asked is, what distance should there be between the rows of rivets, as well as the amount of lap from center of rivet hole to calking edge. The distance between the rows of rivets is not very important, as it will have no bearing on the efficiency of the joint. It is well not to have too great a distance, because of the trouble in keeping the seam tight. Again, it must not be too small, so that one rivet head laps upon another. A good idea is to make the diagonal pitch about equal to the pitch of a single riveted lap seam. This permits the rivet sets or dies to perform their work without cutting the head of an adjoining rivet, and also brings the sheets close together, making a tight joint with a slight amount of calking.

Rule—

$$\frac{6P + 4D}{10} = PD.$$

P = Pitch of rivets in inches.
D = Diameter of rivets in inches.
PD = Diagonal pitch in inches.

If the pitch is 3 inches, with 3/4-inch rivets, the diagonal pitch will be found as follows:

$$\frac{(3 \times 6) + (4 \times 3/4)}{10} = 2.1\text{-inches diagonal pitch. See Fig 4.}$$

Our readers will understand that PD, which in this example is 2.10 inches, is the minimum pitch, and they are privileged to increase it, and cause no decrease in the efficiency of the seam. Too great a pitch (PD) will, as explained, make trouble in having a steam-tight job. Many of our readers have, no doubt, frequently seen seams made tight and then break out in spots a little later on. These leaks are caught only to break out in another place. The diagonal pitch in a case of this kind is generally too great.

To Ascertain the Lap.

The amount of lap is varied according to the ideas of those who handle the work. A short lap is desired, when the seam is exposed to flames or heat, so as to prevent the sheets cracking from the rivet holes to the calking edge. The water being unable to reach the sheet and rivet head directly, causes the material at this point to get hotter, resulting in cracks. Therefore, as short a lap as possible is used when the seam is directly exposed to the fire and heat. Some boiler makers have resorted to counter-sinking the rivet holes, and are driving an oval counter-sunk rivet, as shown in Fig. 6. The rule generally used is to make the lap 1½ times the diameter of the rivet hole. This is sometimes varied by taking 1½ times the diameter of the rivet, which, of course, gives a slightly smaller lap, as the diameter of the rivet is 1/16 inch less than the diameter of the hole.

Circumferential Seams.

The question will arise as to why the circumferential seams can go single riveted. In our boiler the flues extend from head to head, and therefore brace the greater portion of the head. Also the braces extending from shell to head help support the head. Thus the rivets are not subjected to any great strain. If it were a tank with dished heads and no flues or braces to assist the rivets, it will be seen that the stress on the rivets holding the head is not excessive. First, we must find the area of the head which will be the outside diameter of the head squared, times $\frac{3.1416}{4}$

59 9/16 × 59 9/16 × .7854 = 2786.12 square inches, area.

2786.12 × 175 (pounds pressure) = 487,571 pounds, pressure on head. Suppose the head is riveted to the shell with a single row of 3/4-inch rivets which are 13/16 inch when driven.

Area of 13/16 rivets = .5185 square inch. Figuring on

42,000 pounds shearing strength of rivets per square inch, we find one rivet good for:

$$42000 \times .5185 = 21777 \text{ pounds.}$$

$$487571 \div 21777 = 22.4 \text{ number of rivets.}$$

Therefore, 23 rivets, 13/16 diameter, will represent the minimum number of rivets in the circumferential seams. The pitch will be determined as follows:

$$60 \times 3.1416 = 188.5 \text{ inches, circumference.}$$

$$188.5 \div 23 = 8.19 \text{ inches, pitch of rivets.}$$

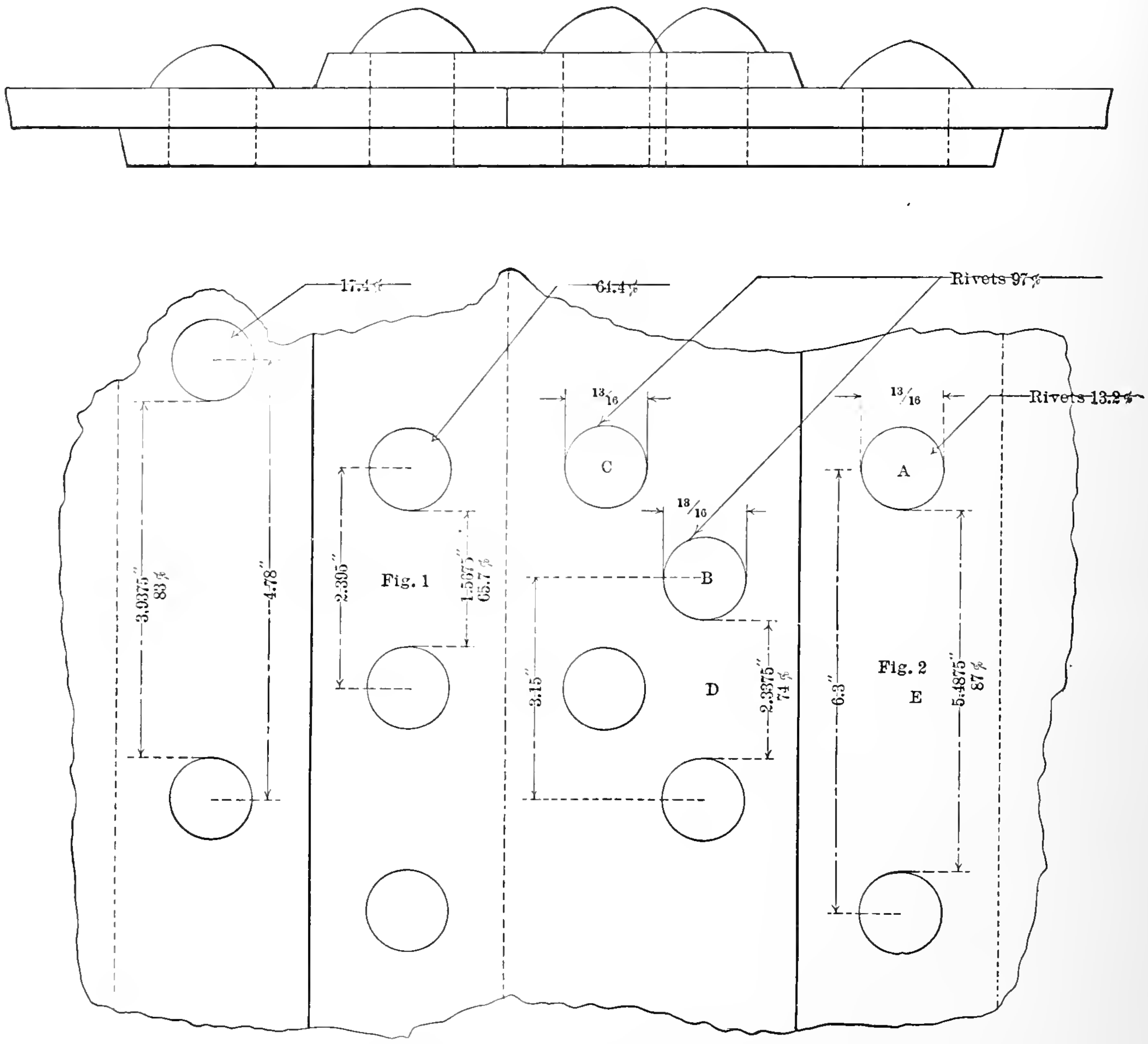
area, providing we use a 2-inch pitch for 94 rivets, in the circumferential seam to stand 2,047,038 pounds. We find the head is subjected to 487,571 pounds pressure with net section of plate good for 2,954,796 pounds. Therefore,

$$2{,}954{,}796 \div 487{,}571 = 6.1 \text{ factor of safety.}$$

$$2{,}047{,}038 \div 487{,}571 = 4.2 \text{ factor of safety.}$$

These examples will throw some light on the reasons for single-riveted circumferential seams. Later on, it will be shown how the plates suffer from other causes.

If 7/8 instead of 3/4 rivets were used in the circumferential



DOUBLE AND TREBLE RIVETED BUTT JOINTS.

This, as will be seen, is out of all reason, or about 3½ times too great a pitch. Therefore, if we use a 2-inch pitch the rivet area creeps up more than three times. The next point is to find whether a 2-inch pitch leaves a sufficient net section of plate.

2 — 13/16 = 1 3/16 inches net section of plate.

1 3/16 × 7/16 = .5195 area of net section.

188.5 ÷ 2 = 94 spaces.

94 × .5195 = 48.833 square inches, total area of net section.

48.833 × 60,000 = 2,929,980 pounds, total strength of net section of plate.

21,777 × 94 = 2,047,038 pounds, total strength of rivets.

We find we have on the head 487,571 pounds and sufficient rivet seams, the area to be supported being the same, the pitch should be increased to about 2⅜ inches:

$$188.5 \div 2.375 = 79.4 \text{ number of rivets.}$$

As a 7/8 rivet equals 15/16 when driven the corresponding area will be .69029 square inch.

42000 × .69029 = 28992.18 pounds, shearing strength of one rivet.

28992.18 × 80 = 2,319,374.4 pounds, total strength.

2319374.4 ÷ 487571 = 4.75 factor of safety.

Therefore, we gain the difference between 4.75 and 4.2, or .55; thus 7/8 rivets at this pitch give more strength than 3/4 rivets at 2 inches. As the strength of the net section of plate is in

excess of the strength of the rivet area, we have only to figure on the rivets in this example.

Butt Joint With Inside and Outside Straps.

Fig. 1 shows a double-riveted butt strap joint, a construction which is far superior to any lap joint. Fig. 2 shows a treble-riveted butt joint with which a very high efficiency can be obtained. Our boiler must stand 175 pounds pressure. With a treble-riveted lap joint we could not get any better than 163 pounds pressure, so that is out of consideration. Let us see if a double-riveted joint, as shown in Fig. 1, will do. We will consider that all our holes are punched small and reamed out. Thus we get a factor of safety of 4 plus ($P = 2$) or 4.20.

Having decided this, our next move is to find the efficiency of joint necessary.

Rule:

A = Radius of boiler.
B = Working pressure.
C = Constant = 100.
D = Thickness of plate in inches.
$T.S.$ = Tensile strength.
F = Factor.
E = Efficiency.

$$\frac{F \times A \times B \times C}{D \times TS} = E$$

$$\frac{4.2 \times 29.78 \times 1.75 \times 100}{.4375 \times 60000} = 83.4\%$$

We must now find out whether a double-riveted butt joint will give us 83.4 percent efficiency or not. First, we will have to ascertain the greatest pitch so we can get the strongest net section of plate, as the efficiency will be figured from the net section of plate at the outer row of rivets. This pitch wil be twice that of the inner row. In Part I we found from the table for the inner row the constant 1.75. Hence by the formula the maximum pitch will be

$(7/16 \times 1.75) + 1\frac{5}{8} = 2.39$, or about $2\frac{3}{8}$ inches.

Therefore the pitch for the outer row will be $2\frac{3}{8} \times 2 =$ 4.75 inches.

$4.75 - .9375 = 3.8125$

$3.8125 \div 4.75 = 80$ percent of net section compared to solid plate.

Having taken the limit in pitch of rivets, we cannot reach the proper efficiency with a double-riveted butt joint with inside and outside straps. Hence this joint will not do for our boiler, as the following computation shows that only a pressure of 166.6 pounds per square inch would be allowed.

$$\frac{60000 \times .80 \times .875}{60 \times 4.2} = 166.6 \text{ pounds, allowable pressure.}$$

With $\frac{3}{4}$ rivets, 13/16 holes, the efficiency will be as follows:

$4.75 - .8125 = 3.9375$ net section of plate.

$3.9375 \div 4.75 = 83$ percent efficiency.

$$\frac{60000 \times .83 \times .875}{60 \times 4.2} = 173 \text{ pounds, allowable pressure.}$$

Here, however, another feature presents itself. The net section of plate might be strong enough, but the rivet area would very likely be too small.

Steel plate, tensile strength per square inch of section 60,000 pounds.

Thickness of plate $7/16 = .4375$.
Diameter of rivet holes $13/16 = .8125$.
Area of rivet hole $= .5185$.
Pitch of inner row $= 2\frac{3}{8}$ inches.
Pitch of outer row $= 4\frac{3}{4}$ inches.
Resistance of rivets in single shear $= 42000$ pounds.

Resistance of rivets in double shear = 85 percent excess over single shear, or 77700 pounds.

$4.75 \times .4375 \times 60000 = 124687.5$ pounds, strength of solid plate.

$4.75 \div .8125 = 3.9375$ net section of plate.

$3.9375 \times .4375 \times 60000 = 103359.375$ pounds, strength of net section of plate.

$.5185 \times 2 \times 77700 = 80574.9$ pounds, strength of two rivets in double shear.

$.5185 \times 42000 = 21777$ pounds, strength of one rivet in single shear.

$80574.9 + 21777 = 102351.9$ pounds, total strength of rivets.

Therefore the rivet strength is the weaker.

$102351.9 \div 124687.5 = 82$ percent, efficiency of rivets.

$103359.375 \div 124687.5 = 83$ percent, efficiency of plate.

Again, if $\frac{7}{8}$ rivets were used, and the rivet efficiency increased, the efficiency of the net section of the plate would be decreased.

$4.75 - .9375 = 3.7125$ inches.

$3.8125 \times .4375 \times 60000 = 100078.125$ pounds, strength net section of plate.

$100078.125 \div 124687.5 = 80$ percent efficiency with $\frac{7}{8}$ rivets.

Another rule which the author believes is quite simple is as follows:

A = Area of one rivet.
B = 1.85 constant for rivets in double shear.
B' = 1 constant for rivets in single shear.
P = Pitch for outer row of rivets.
P' = Pitch for inner row of rivets.
C = Shearing strength of rivets.
C' = Tensile strength of plate.
T = Thickness of plate in inches.
$\%$ = Percent of rivet strength compared to solid plate.
E = Number of rivets in one pitch in inner row.
E' = Number of rivets in one pitch in outer row.

$$\frac{A \times B' \times C \times E'}{P \times T \times C} + \frac{A \times B \times C \times E}{P' \times T \times C'} = \%$$

$$\frac{.5185 \times 42000 \times 1}{4.75 \times .4375 \times 60000} = 17.5 \text{ percent}$$

$$\frac{.5185 \times 1.85 \times 42000}{2.375 \times .4375 \times 60000} = 64.5 \text{ percent}$$

64.5 + 17.5 = 82 percent, efficiency of rivets.

Our readers will see that the net section of plate with 13/16 holes, 4¾-inch pitch, gives an efficiency of 83 percent, but the rivets only give 82 percent. It is necessary for the rivet percent to be in excess of the percent of the net section of plate. There are three places where the joint can fail when the rivets and the net section of the plate are nearly alike.

1. It can break through net section of plate at outer row of rivets. (This we found had an efficiency of 82 percent.)

2. It can shear the rivets (which we found had an efficiency of 82 percent).

3. It can break the net section of the plate at the inner row of rivets and shear the outer row of rivets; which are in single shear. (The following computation will show that this has an efficiency of 83 percent.)

2.375 — .8125 = 1.5625.

1.5625 ÷ 2.375 = 65.8 percent, efficiency of net section of plate at inner row.

65.8 + 17.4 = 83.2 percent.

Therefore the strength of rivets is the weaker.

Let us figure the joint first with ⅞ rivets. On page 4 the constant for obtaining the pitch is 3.5. Therefore (7/16 × 3.5) + 1⅝ = 3.15 inches, maximum pitch for inner row of rivets.

3.15 × 2 = 6.30 inches, pitch for outer row.

$$\frac{A \times B' \times C \times E'}{P \times T \times C'} + \frac{A \times B \times C \times E}{P' \times T \times C'} = \%$$

$$\frac{.69 \times 1 \times 42000 \times 1}{6.30 \times .4375 \times 60000} = 17.5 \text{ percent}$$

$$\frac{.69 \times 1.85 \times 42000 \times 2}{3.15 \times .4375 \times 60000} = 130 \text{ percent}$$

130 + 17.5 = 147.5 percent, strength of rivets compared to plate.

6.30 — .9375 = 5.3625.

5.3625 ÷ 6.30 = 85 percent, efficiency of net section of plate at outer row of rivets.

3.15 — .9375 = 2.2125.

2.2125 ÷ 3.15 = 70 percent, efficiency of net section of plates at inner row of rivets.

70 + 17.5 = 87.5 percent, strength of net section of plate at inner row and shearing of outer row of rivets. Therefore, net section of plate at outer row is the weakest point.

As our rivet area is far in excess of plate, we can use a larger pitch for the rivets. By doing so we can increase the efficiency of the net section of the plate. As the pitch of rivets increases so does the net section of plate, and this increases the efficiency of plate, but the increased pitch cuts down the percentage strength of rivets.

If ¾ rivets, 13/16 holes had been used instead of ⅞ rivets, 15/16 holes, the result would have been as follows:

$$\frac{.5185 \times 1.85 \times 42000 \times 2}{3.15 \times .4375 \times 60000} = 97 \text{ percent}$$

$$\frac{.5185 \times 1 \times 42000}{6.30 \times .4375 \times 60000} = 13.2 \text{ percent}$$

97 + 13.2 = 110.2 percent, strength of rivets compared to plate. We find a large cut in rivet percentage, yet it is above the plate.

6.30 — .8125 = 5.4875.

5.4875 ÷ 6.30 = 87 percent, efficiency of net section of plate at outer row.

3.15 — .8125 = 2.3375.

2.3375 ÷ 3.15 = 74 percent, efficiency of net section of plate at inner row. To this we add the percent of rivet strength of one rivet in single shear at the outer row. Thus 74 + 13.2 = 87.2, or about 87 percent. Therefore, the breakage will occur at net section of plate at outer row of rivets as this is the weakest point.

Fig. 2 shows the layout of rivet holes when 13/16 inch in diameter.

A = Rivet in single shear with a 13.2 percent value.

B and *C* = Rivets in double shear with a 97 percent value.

A, *B* and *C* = Combined strength (13.2 + 97 percent = 110.2 percent).

E = Net section of plate at outer row with 87 percent.

D = Net section of plate at inner row with 74 percent.

A and *D* together equal 87.2 percent. It is the assistance derived from the rivet *A* that prevents *D* from being the weakest point. If the inner strap did not extend out, taking in the row of rivets *A* in single shear, the net section at *D* would be the efficiency of the joint, or 74 percent.

The following computation will show what pressure may be allowed on the boiler with this joint:

$$\frac{60000 \times .87 \times .875}{60 \times 4.2} = 181 \text{ pounds, pressure allowed with ¾-inch rivets.}$$

$$\frac{60000 \times .85 \times .875}{60 \times 4.2} = 177 \text{ pounds, allowed with ⅞-inch rivets.}$$

In the preceding articles the efficiencies of both lap and butt-joint seams have been found for different sizes of rivets. With the treble-riveted butt joint with inside and outside straps, ¾-inch rivets, a factor of safety of 4.2, tensile strength of the plate 60,000 pounds per square inch, and thickness of plate 7/16 inch, the boiler under consideration was found good for 181 pounds per square inch steam pressure. The strength of a section of plate, the length of one pitch of rivets, is equal to 60,000 × 5.4875 × 1.4375 = 144,047 pounds. The stress on a similar section of the boiler shell, due to a steam pressure of 181 pounds, is equal to $\frac{60 \times 6.3 \times 181}{2}$ = 34,209 pounds. Thus we have a stress of 34,209 pounds upon a section capable by the former gives, of course, the factor of safety, 144,047 ÷ 34,209 = 4.2 factor of safety. This, as will be seen, checks the other calculations.

Thickness of Butt Straps.

To ascertain the thickness of butt straps, the area of a section of the strap at its weakest point for one pitch may be made equal to the area of the section of the plate at its weakest point for one pitch. The weakest point in the butt straps is along the line of holes nearest to where the plates butt, since this section receives no assistance from the shearing strength of the rivets. The weakest point in the plate is at the outer row of rivets.

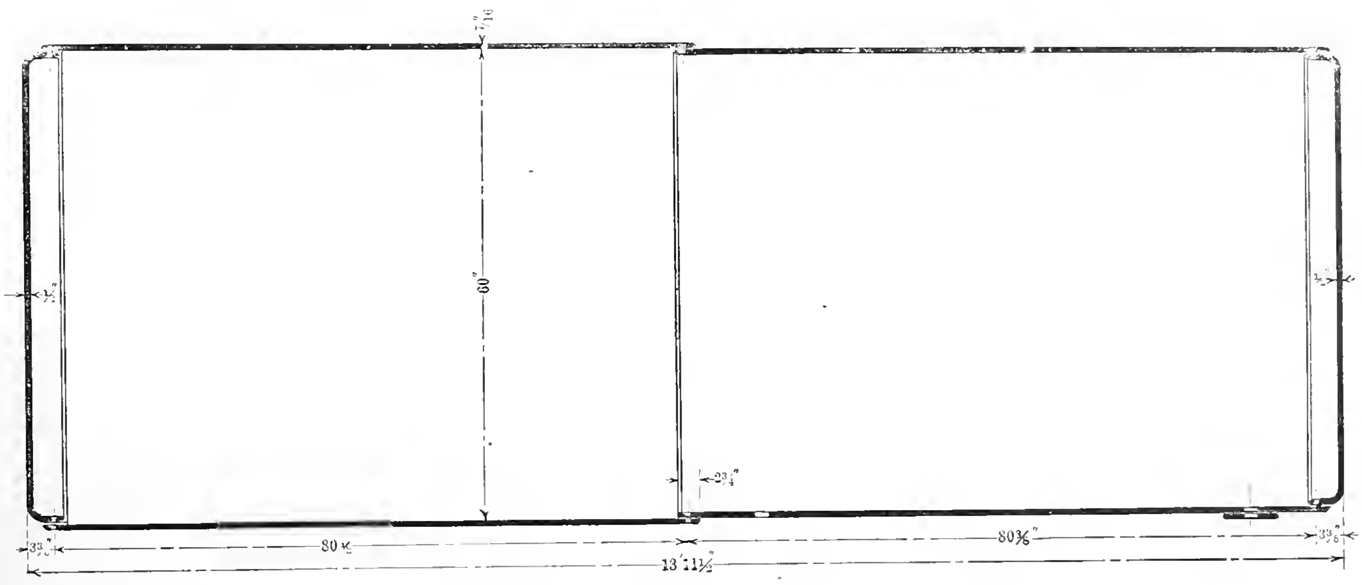


FIG. 9.—SECTION SHOWING OUTLINE OF BOILER SHELL AND HEADS.

If A = net section of plate at outer row.
B = thickness of plate.
C = net section of plate at inner row.
D = thickness of straps.

$$\text{Then } D = \frac{A \times B}{C}.$$

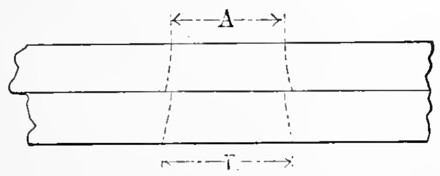


FIG. 10.—EFFECT OF PUNCHING HOLES IN LIGHT PLATE.

$$\frac{5.4875 \times .4375}{2.3375 \times 2} = .514 \text{ inch, thickness of both straps.}$$

$.514 \div 2 = .257$ inch, thickness of one strap.

This is a fraction over ¼ inch thickness. As it is the minimum thickness, it would be better to make the straps at least ⅜ inch thick. Frequently the thickness of the strap is made ⅝ the thickness of the plate.

Welded Joints.

It has been generally proved in actual tests that welded joints are unreliable, due to the uncertainty of the weld. Even where perfect welds have been made, the strength of the joints has not proved equal to the strength of the plate. Since the main idea in boiler construction should be to make all parts of as nearly equal strength as possible, it would not be good practice to use a joint whose strength is uncertain.

In the preceding articles we have found by means of different formulæ and different methods of doing work, the pressure which would be allowed on the boiler under different conditions. Actual conditions will upset these calculations to a certain extent, as it will be found impossible in general work to calculate the distances such that the rivet holes can be stepped off exactly to the pitch as found by the formulæ. It may be a fraction one way or the other, and this will effect the percentage of strength to a slight extent; thus it will be seen that both a scientific and practical education are of great importance for the layer out, in order that he may know what the effect on the efficiency of the joint will be when he finds it necessary to increase or decrease the pitch of rivet holes to cover a certain distance. It is quite impossible to make laws or rules defining the exact pitch for the strength of all the joints, for the reason that the pitch in nine cases out of ten cannot be stepped off in equal spaces. Only the maximum pitch allowable for a certain size of plate can be fixed exactly.

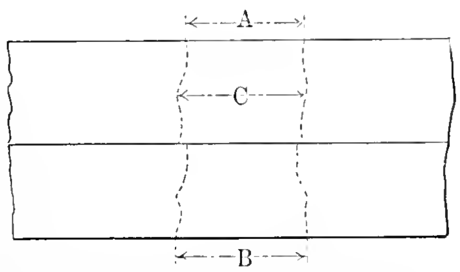


FIG. 11.—EFFECT OF PUNCHING HOLES IN HEAVY PLATE.

Preceding examples have shown the effect on the percentages produced by punching holes full size, by punching small and reaming out, and also by drilling in place. Another feature must be taken into consideration, and that is the damage done by punching. On light plates the damage is not great, but it increases as the plates increase in thickness. It is estimated that holes punched full size damage the strength of plates from about 8 percent in ¼-inch plates to 33 percent

in ¾-inch plates. In plates having the holes punched small and reamed out, this damage is obviated to a large extent. Actual experiments show that the punched holes make the plate between the rivet holes less in tensile resistance according to the thickness of the plates from 6 to 20 percent.

It is utterly impossible for each and every hole to be fair regardless of the care exercised in laying out. This is due partly to the great variation in the thickness of plates. The thickness of every plate is greater at the center than at the edge, and the wider and thinner the plate the greater is this variation. This variation will certainly have its effect when the sheet is rolled up; also the punching may cause the hole to vary slightly, so that when the sheet is connected some of the holes may be slightly unfair.

In Fig. 10 is shown the section of a rivet hole punched full size in a light plate. In light plates, with good punches and

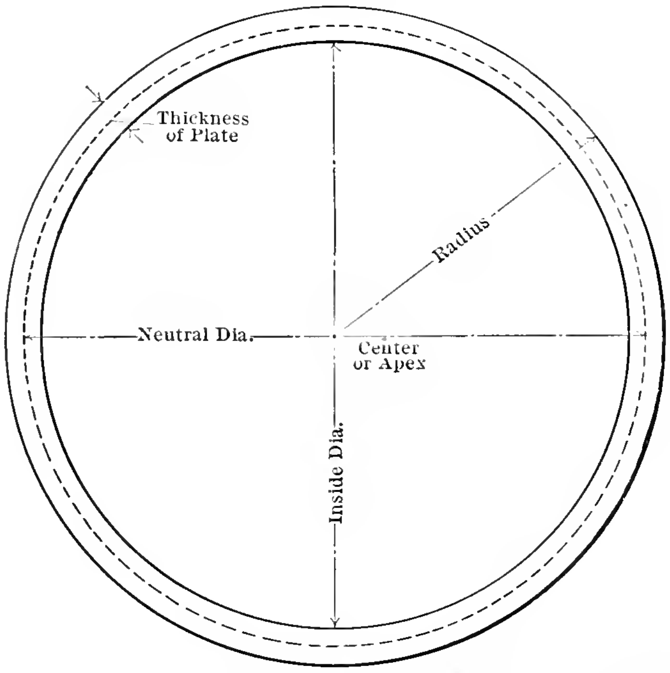


FIG. 12.—SECTION SHOWING DIMENSIONS OF SHELL PLATE.

dies, the holes will be slightly tapered. In heavy plates the metal is so compressed that it will tear the sheet in the center of the thickness of the plate, causing the diameter of the holes to vary according to the thickness of the plate. A section of holes punched full size in heavy plates is shown in Fig. 11. *C* is ⅛ inch greater in diameter than *A*, and is also larger than *B*. It will readily be seen how difficult it is to upset rivets so as to fill the entire hole. Rivets driven in holes of this shape will leak, since the holes are not properly filled. It is almost impossible to remove or knock out one of these rivets after its head has been cut off. The effect of all such conditions upon the factor of safety has been clearly shown by the preceding examples.

Size of Shell Plates.

Since the boiler under consideration is 60 inches in diameter and 14 feet long, the shell can be made in two equal courses. The circumference to be used for the length of the plates may be found by multiplying the inside diameter of the boiler by 3.1416, and adding to the result three times the thickness of the plate, by multiplying the outside diameter of the boiler by 3.1416 and subtracting three times the thickness of the plate, or by multiplying the mean diameter of the boiler measured to the center of the thickness of the plate by 3.1416. The latter method is the correct one to use. Since the inside diameter is 60 inches, and the thickness of plate 7/16 inch, the mean diameter will be 60 7/16 inches. The circumference corresponding to this diameter is 189.87 inches. If the circumference corresponding to the inside diameter had been found and three times the thickness of the plate added, the result would have been 189.81 inches. If the circumference corresponding to the outside diameter had been found and three times the thickness of the plate subtracted, the result would have been 189.93 inches.

The circumference, 189.87 inches, will be the length of the plate for a butt joint. For a treble-riveted lap joint the dis-

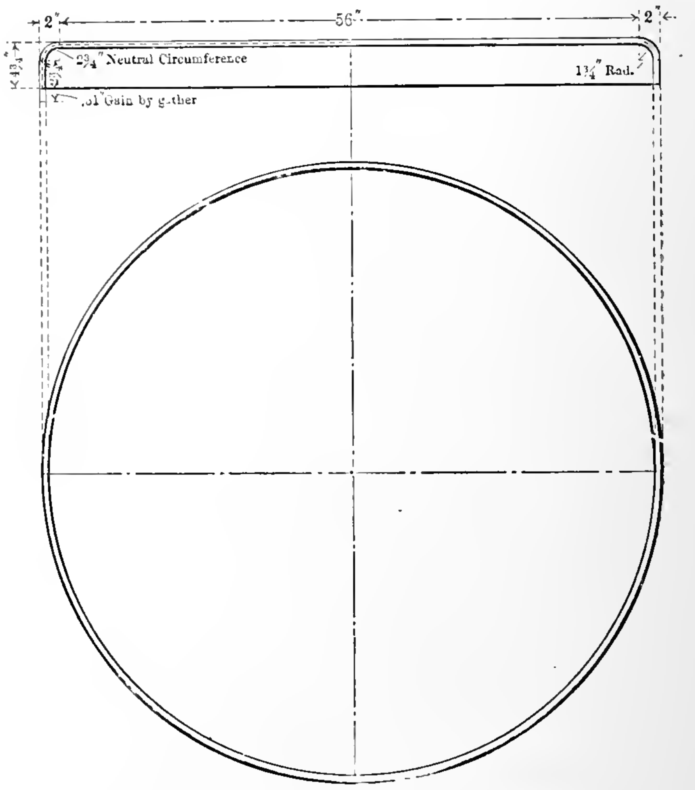


FIG. 13.—PLAN AND ELEVATION OF HEAD.

tance between the rivet holes and the laps must be added. Assuming a distance between rivet holes of 1⅝ inches and a lap of 1⅜ inches, the length of the plate would be

$$189.87 + 2 \times 1\tfrac{5}{8} + 2 \times 1\tfrac{3}{8} = 189.87 + 6 = 195.87 \text{ inches.}$$

This would be the length for the large course. Make the small course six times the thickness of the plate shorter. It is a good idea to allow ⅜ inch more for squaring up the sheet, making the total length about 196¼ inches.

In determining the length of the boiler we will figure on using 14-foot flues. It will be necessary to make allowance for the beading of the flues, which would require, roughly, ¼ inch at each end, making ½ inch in the total length; therefore, the length of the boiler from outside to outside of the heads will be 13 feet 11½ inches.

We will assume that the heads are to be flanged to a 2-inch outside radius. It has been previously decided to make the laps 1⅜ inches; therefore, to prevent the calking edge of the plate extending onto the curved part of the flange, the gage line for the rivets on the head should be $2 + 1\frac{3}{8} = 3\frac{3}{8}$ inches from the outside of the head. Therefore, for both heads, the total distance will be $2 \times 3\frac{3}{8} = 6\frac{3}{4}$ inches. Subtracting 6¾ inches from 13 feet 11½ inches for the distance

between the rivet lines in the heads leaves 13 feet 4¾ inches, or 160¾ inches. Dividing 160¾ by 2 we get 80⅜ inches as the width of each shell plate from center to center of the circumferential seams. For the total width of these plates add the laps.

$$1\tfrac{3}{8} \times 2 = 2\tfrac{3}{4} \text{ inches.}$$
$$80\tfrac{3}{8} + 2\tfrac{3}{4} = 83\tfrac{1}{8}.$$

Add an allowance, say ⅜ inch, making the total width of the plate 83½ inches. Some do not make such a great allowance.

Size of Heads.

Some authorities have certain stated thicknesses of heads for certain diameters of boilers. The heads should be at least as heavy as the shell, and in most cases slightly heavier. Let us make the heads ½ inch thick in the boiler under consideration. The pressure this plate will stand will be figured out

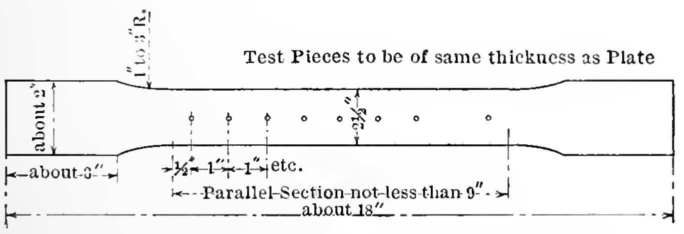


FIG. 14.—STANDARD TEST PIECE FOR BOILER PLATE.

when laying out the braces and flue pitches. The majority of shops order boiler heads equal in diameter to the length of a cross-section of the flanged head measured at the center of the thickness of the plate. This is not bad practice, but it allows a fraction more than is necessary.

If A = outside diameter of the head.
B = outside radious of the flange.
C = ¼ circumference of the flange at the center of the thickness of the plate.
D = ½ of $A - B$.
$E = F - B$.
F = depth of flange.
16 = constant.

Then, as seen from Fig. 13, the length of a cross-section of the flanged head measured at the center of the thickness of the plate will be $2D + 2C + 2E$.

$$56 + 2 \times 2.75 + 2 \times 2.75 = 67 \text{ inches.}$$

This, according to the above rule, would be the diameter of the head before flanging. The writer has originated the following rule for determining the amount which would be gained in this length in the operation of flanging:

$$\frac{\dfrac{E+C}{2} \times 16}{F \times \frac{1}{2}A} = \text{gain in flanging.}$$

$$\frac{\dfrac{2.75 + 2.75}{2} \times 16}{4.75 \times 30} = \frac{88}{285} = .31$$

Therefore, .31 equals the amount to be taken off all around, due to the gain caused by the gather of the material when flanged. Thus 67 — .31 = 66⅝ inches diameter. This is for the large head. Since the small head is ⅞ inch less in diameter a similar calculation should be made for it.

Having figured out the shell sheets and heads we will make up the bill of material as follows:

Material required for one 60-inch by 14-foot tubular boiler with butt joints:

One sheet, 7/16 inch by 83½ inches by 190¼ inches, for large course.

One sheet, 7/16 inch by 83½ inches by 187⅝ inches, for small course.

One sheet, ½ inch by 66⅝ inches diameter, for large head.

One sheet, ½ inch by 65¾ inches diameter, for small head.

In recent years steel has supplanted iron in boiler construction. Its use has become universal, because it can be manu-

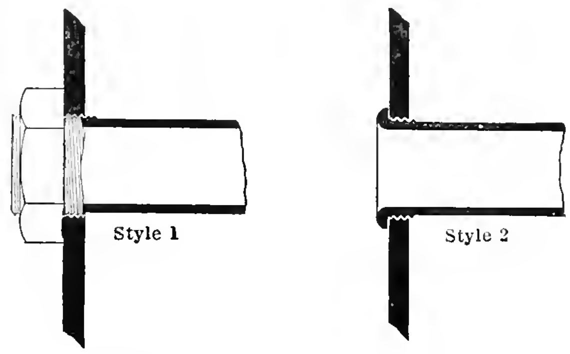


FIG. 15.—TWO METHODS OF FASTENING STAY-TUBES.

factured more cheaply than iron, and thinner sheets may be used, since its tensile strength exceeds that of iron. It is as ductile and more homogenous than iron.

The following standard specifications for open-hearth plates were adopted by the Association of American Steel Manufacturers:

Special Open-Hearth Plate and Rivet Steel.

Steel shall be of three grades: extra soft, fire-box and flange or boiler.

Extra Soft Steel.

Ultimate strength, 45,000 to 55,000 pounds per square inch; elastic limit, not less than one-half the ultimate strength; elongation, 26 percent; cold and quench tests, 180 degrees flat on itself, without fracture on outside of bent portion; maximum phosphorus, .04 percent; maximum sulphur, .04 percent.

Fire-Box Steel.

Ultimate strength, 52,000 to 62,000 pounds per square inch; elastic limit, not less than one-half the ultimate strength; elongation, 26 percent; cold and quench bends, 180 degrees flat on itself, without fracture on outside of bent portion; maximum phosphorus, .04 percent; maximum sulphur, .04 percent.

Flange or Boiler Steel.

Ultimate strength, 55,000 to 65,000 pounds per square inch; elastic limit, not less than one-half the ultimate strength; elongation, 25 percent; cold and quench bends, 180 degrees flat on itself, without fracture on outside of bent portion; maximum phosphorus, .06 percent; maximum sulphur, .04 percent.

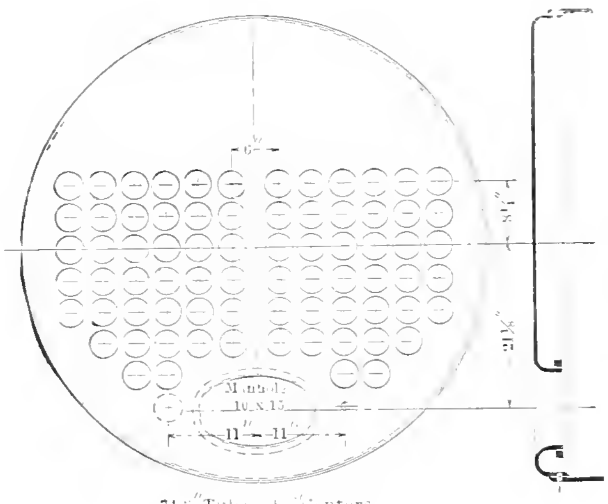
Steel for boiler rivets shall be made of the extra soft grade

specified above. All tests and inspections shall be made at place of manufacture prior to shipment. The tensile strength, limit of elasticity and ductility shall be determined from a standard test piece, cut from the finished material, the standard shape of this test piece for sheared plates to be as shown in cut, Fig. 14. Test coupons cut from other material than plates may be the same as those for the plates, or they may be planed or turned parallel throughout their entire length. The elongation shall be measured on an original length of 8 inches, except in rounds of ⅝ inch or less in diameter, in which case the elongation shall be measured in the length equal to eight times the diameter of section tested. Four coupon pieces shall be taken from each melt of finished material, two for tension and two for bending.

Material, which is to be used without annealing or further treatment, is to be tested in the condition in which it comes from the rolls. When material is to be annealed, or otherwise treated, before use, the specimen representing such material is to be similarly treated before testing. Every finished piece of steel shall be stamped with the melt number. All plates shall be free from surface defects, and to have a workman-like finish.

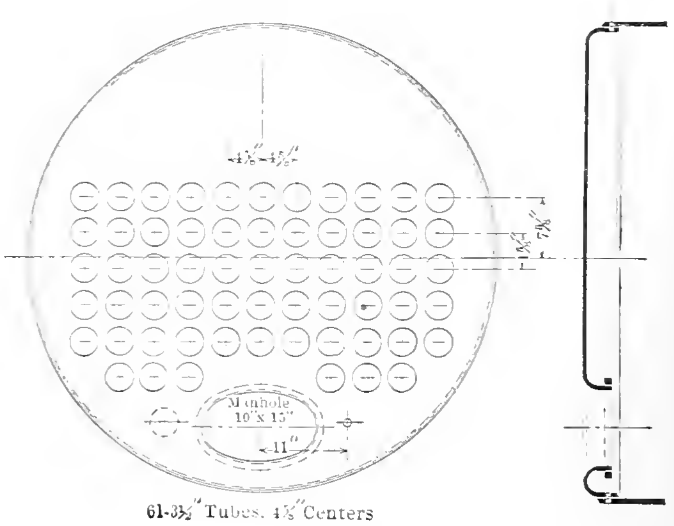
Each boiler inspection and insurance company has its own specifications for the material which is used in boilers built according to its rules. These are all of the same general character as the set already quoted.

Having fully decided about the plates, and sent the order to the mills to be filled, we will now direct our attention to the flues. Tubular boilers derive their heating surface mostly from the flues. The smaller the flues the more that can be put in, and this naturally makes more heating surface. Locomotive boilers have small flues for this reason, as the ratio of heating surface to grate area in a locomotive boiler is greater than in tubular boilers. Tubes of tubular boilers are laid out in vertical and horizontal rows. It is customary in some districts to have a manhole in the front head. This is a splendid feature, as it permits of inside inspection as well as permitting the boiler to be thoroughly cleaned, and, furthermore, in case of repairs to the bottom of the shell the work can be done without removing the tubes, except in large repairs, when only a portion will have to be removed.



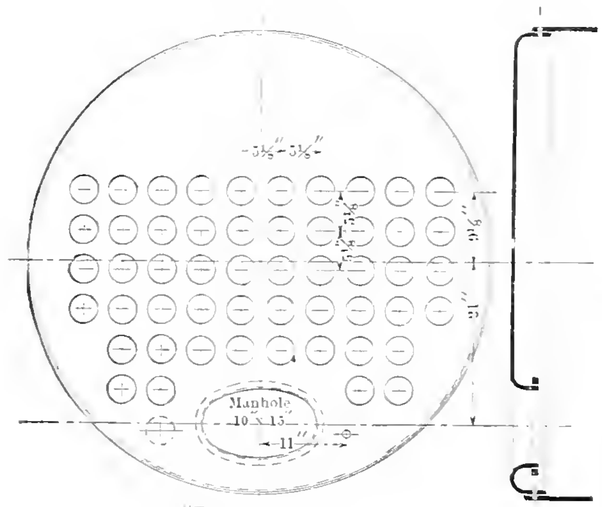
74-3" Tubes 4½" Centers

FIG. 16.



61-3½" Tubes, 4½" Centers

FIG. 17.



52-4" Tubes, 5⅜" Centers

FIG. 18.

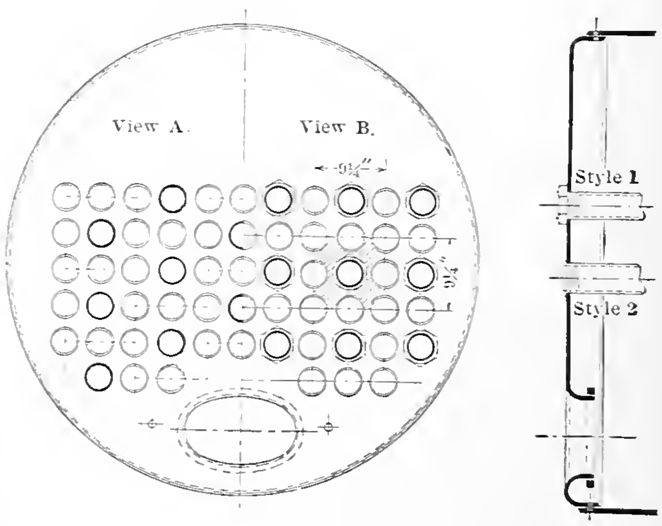


FIG. 19.

Layout of Tubes.

In Fig. 16 is shown the layout of 3-inch tubes, seventy-four in number. It will be noticed that there is a large space in the center. Many desire this, as they believe this space causes a better circulation of the water. Fig. 17 shows the layout of 3½-inch tubes, sixty-one in number. This layout, as will be noted, has one row in the center. Fig. 18 is the layout of 4-inch tubes, fifty-two in number. They are laid out with the same amount of space in the center as there is between the other rows of tubes. It will be noted in Figs. 16, 17 and 18 that on

one side of the manhole the location of an end to end stay is shown, while on the other side is a flue shown dotted. The flue used in place of the end to end stay is a poor construction, as will be seen later on. When a manhole is not located in the front head, a greater number of flues can be placed in the boiler. For instance, if the manhole were omitted in Fig. 16 an additional row of flues could be put in, giving ten more flues; likewise in Fig. 17, two additional rows could be put in, giving thirteen more flues. In Fig. 18, one more row, making ten additional flues, could be used in place of the manhole.

Holding Qualities of Flues.

Experiments show that the holding qualities of flues expanded in the flue sheets vary very greatly. As the thickness of the head will have a bearing on this, no set rule can be made governing same. Much depends on the grade of workmanship performed. Ordinarily the flue expanded into the flue sheet will be perfectly safe. Experiments show that the mere beading of the flues increases the factor from 200 to 400 percent. This being the case, it is needless to say that this should be done when so much can be gained by so little trouble and work. If the flue could be fastened at the ends, so as to make the flue body the weakest point, it would be quite easy to figure out the strength of the flue and the stress to which it could be subjected. This could be figured in the same manner as the braces.

The holding qualities of flues has been proven as safe for boilers of small diameters, but large boilers should be stayed with stay-tubes. Fig. 19 shows two views of stay-tubes, with two modes of fastening them to the flue sheet. On the right-hand side, Fig. 19, view *B*, is the layout, showing the area that a stay-tube will support. The stay-tubes are shown with nuts, but can be applied as in view *A* by screwing into the sheet and beading over. There are two different values allowed, according to the method used. It will be seen that when the stay-tubes are laid out as in view *B* they form a much better support for the boundary rows of flues than in view *A*. Fig. 15 is an enlarged view, showing how the flues are fastened to the flue sheets.

The British marine rules for stay-tubes are as follows:

T = The thickness of plate is sixteenth of an inch.

P = The horizontal pitch, center to center of boundary rows.

C = Constant.

The formula is as follows:

$$\frac{C \times T \times T}{P \times P} = \text{working pressure.}$$

C = 120 when the stay-tubes are pitched with two plain tubes between them and not fitted with nuts on the outside of plates.

C = 130 when they have nuts on the outside of plate.

C = 140 if each alternate tube is a stay-tube not fitted with nuts.

C = 150 when they are fitted with nuts, outside the plates.

C = 160 if every tube is a stay-tube, and not fitted with nuts.

C = 170 if every tube in these rows is a stay-tube and each alternate stay-tube is fitted with nuts, outside the plates.

Assuming that the boiler had 3½-inch tubes, laid out as in Fig. 17, with ½-inch flue sheet and tubes fitted with nuts as in view B, every other tube being a plain tube, the working pressure would be found as follows. The constant in this case is 140:

$$\frac{140 \times 81}{85.6} = \frac{11,340}{85.6} = 132.5 \text{ pounds.}$$

NOTE.—Boilers of 60 inches diameter do not require stay-tubes.

What pressure is the stay-tube subjected to, laying aside any assistance derived from the plain tubes? As the centers of our tubes are 4⅝ inches, the stay-tube centers would be twice as great, or 9¼ inches. Thus 9¼ inches by 9¼ inches = 85.6 square inches. This would not be the actual area exposed to pressure, as there are some deductions to make, consisting of one 3½-inch hole, four half holes 3½ inches diameter, and four quarter holes, 3½ inches diameter. Adding these results together we have four 3½-inch holes. To find the area we multiply 3½ inches by 3½ inches by .7854 = 9.621 square inches.

The area of one tube being 9.621, the area of four tubes would be 4 × 9.621 = 38.484 square inches. Therefore, 85.6 — 38.484 = 47.116 square inches.

Total pressure to each stay-tube is 47.116 × 175 pounds = 8245.3 pounds per stay-tube. Assuming that the metal of the stay-tube has 60,000 pounds tensile strength per square inch, let us see if a tube ⅛ inch thick is thick enough.

Three-inch flue, ⅛ inch thick, equals 3¼ inches inside diameter and 3⅜ inches neutral diameter. Thus, 60,000 × ⅛ inch × 3⅜ inches × 3.1416 = 79,500.

$$\frac{79,500}{8245.3} = 9.64 \text{ factor.}$$

Thus we see that stay-tubes ⅛ inch thick are thick enough. Since tubes are in a measure braces they should have a factor as high as braces, which is figured as 7 or 8.

Heating Surface.

The heating surface of a boiler includes the tubes and the parts of the shell and heads which are exposed to the flames and gases. The following general rule for calculating the amount of heating surface covers all parts exposed to the flames and gases:

Multiply two-thirds of the circumference of the shell in inches by its length in inches. Multiply the number of tubes by the length in inches. Multiply this product by the inside diameter × 3.1416. Add to these products two-thirds of the area of the tube sheets or heads. Then subtract from this sum twice the area of the tubes. This product gives the number of square inches. To find the number of square feet divide by 144. Take as an example, the boiler with the layout of tubes 3 inches diameter, seventy-four in number:

A = Circumference of shell in inches.

B = Length of shell in inches.

C = Heating surface of shell in square inches.

D = Circumference of tube in inches.
E = Heating surface of tubes in square inches.
F = Area of one head in square inches.
G = Two-thirds of the area of both heads in square inches.
H = Area of all tubes in square inches.
I = Total heating surface.

Some mechanical engineers figure that the area of the head should be figured from the outside diameter of the boiler, while others the outside diameter of the head, which is the inside diameter of the boiler. This, however, does not have a great bearing on the final number of square feet.

Working out the boiler to the letters A, B, C, D, E, F, G, H and I we will have the following:

$A = 60\frac{7}{8}$ inches $\times$ 3.1416 = 191.25 inches.
B = 14 feet $\times$ 12 inches = 168 inches.
$C = 191.25 \times 168 \times 2/3 = 21{,}420$ square inches.
$D = 2\frac{3}{4}$ inches $\times$ 3.1416 = 8.64 inches.
$E = 74 \times 168 \times 8.64$ inches = 107412.48 square inches.
$F = 60\frac{7}{8} \times 60\frac{7}{8} \times .7854 = 2910.5$ square inches.
$G = 2/3 \times 2 \times 2910.5$ square inches = 3880.66 square inches.
$H = 2\frac{3}{4}$ inches $\times$ $2\frac{3}{4}$ inches $\times$ 74 $\times$ .7854 = 439.52 square inches.

Thus our formula will read as follows:

$$\frac{C + E + G - 2 \times H}{144} = I$$

Substituting values, we have

$$\frac{21{,}420 + 107{,}412.48 + 3880.66 - 2 \times 439.52}{144} = 915.55 \text{ sq. ft.}$$

EXPLANATION OF BURSTING AND COLLAPSING PRESSURE.

Flues are subjected to external pressure, while the boiler shell is subjected to internal pressure. There is considerable difference between them. Excess pressure on a boiler shell will result in bursting the shell, while on a flue it will cause a collapse. The shell of a boiler may be out of round but the pressure will tend to round it out to its true shape unless the shell is braced to resist such a stress.

The pressure on a flue being equal on all sides, it would appear reasonable to presume that the pressure on one side would offset the pressure on the other side. This is not actually the case, however, as the working of the boiler causes shocks, and once the flue assumes any shape other than that of a perfectly true cylinder, it is easy prey to the pressure and will result in a collapse.

This explanation will show the prime necessity of having all flues and furnaces that are subjected to external pressure made perfectly true in diameter. The United States allows 225 pounds pressure on all lap-welded flues up to 6 inches diameter, if the material conforms to the following table:

O. Dia. Ins.	Thickness. Ins.	O. Dia. Ins.	Thickness. Irs.	O. Dia. Ins.	Thickness. Ins.
1	.072	$3\frac{1}{4}$	.120	9	.180
$1\frac{1}{4}$	.072	$3\frac{1}{2}$	.120	10	.203
$1\frac{1}{2}$	.083	$3\frac{3}{4}$	.120	11	.220
$1\frac{3}{4}$	.095	4	.134	12	.229

O. Dia. Ins.	Thickness. Ins.	O. Dia. Ins.	Thickness. Ins.	O. Dia. Ins.	Thickness. Ins.
2	.095	$4\frac{1}{2}$	.134	13	.238
$2\frac{1}{4}$	.095	5	.148	14	.248
$2\frac{1}{2}$	.109	6	.165	15	.259
$2\frac{3}{4}$	.109	7	.165	16	.270
3	.109	8	.165	....	....

Flues above 6 inches diameter are allowed other values.

COLLAPSING PRESSURES OF FLUES.

Prof. Reid T. Stewart, of Allegheny, Pa., has conducted extensive experiments to ascertain the collapsing pressures of flues, and has deduced several formulæ, which tend to show that all previous formulæ are more or less incorrect. The general practice has been to take into consideration the length of the flue or furnace from end to end, ring to ring or joint to joint. Figuring on the total length has been found as incorrect, as flues and furnaces do not collapse their entire length.

Experiments conducted by Prof. Stewart demonstrate that long flues will collapse at one point and the balance of flue be perfectly true. The extent that the rigid ends will support the flue cannot be fully determined. It is true that when the flue or furnace is of great length it derives no assistance from the rigid ends. The assistance derived from the rigid ends cannot be taken into consideration, as it does not extend far enough to be accepted as any value.

After a great many tests Prof. Stewart has advanced the following formula B:

$$P = 86{,}670 \frac{T}{D} - 1{,}386. \qquad (B)$$

P = Collapsing pressure in pounds per square inch.
D = Outside diameter of tube in inches.
T = Thickness of wall in inches.

Formula A:

$$P = 1000 \left(1 - \sqrt{1 - 1600 \frac{(T)^2}{(D)^2}} \right) \qquad (A)$$

Formula A is for values less than 581 pounds, or for values of $\frac{T}{D}$ less than 0.023. Formula B is for values greater than these.

Prof. A. P. Carman, of the University of Illinois, has conducted experiments upon the collapsing of flues, and has advanced the following formulæ:

$$P = 50{,}200{,}000 \frac{(T)^3}{D}$$ for thin, cold-drawn seamless tubes.

$$P. = 95{,}520 \frac{T}{D} - 2{,}090$$ for seamless cold-drawn tubes having a ratio of $\frac{T}{D}$ greater than .03.

A formula advocated is to add to the length of the furnace expressed in feet the unit 1. Taking the British Columbia Rule, we have

$$\frac{C \times T^2}{(L + I) \times D} = B$$

C = Constant.
T = Thickness of plate in inches.
L = Length of furnace in feet.
B = Working pressure per square inch, which must not exceed the value $\frac{1{,}000 \times T}{D}$

11,250 is allowed for the constant (C) when the longitudinal seam is welded or fitted with double butt straps, single riveted.

FORMULÆ.	Diameter of Flue.	Thickness of Flue.	Collapsing Press.	Style of Flue
$P = \frac{86670\ T}{D} - 1386$	3″	.109	1763	Lap weld Bessemer steel
	$3\frac{1}{2}$″	.120	1585	
	4″	.134	1517	
$P = \frac{95520\ T}{D} - 2090$	3″	.109	1348	Seamless cold drawn steel.
	$3\frac{1}{2}$″	.120	1176	
	4″	.134	1100	

It will be seen that the length represented by (L) has added to it the unit (1). The adding of the unit (1) is not correct, as it will readily be seen that if the length of the furnace is 3 feet an increase of 33 1/3 percent has been added, or if the furnace is 4 feet long and the unit (1) is added, the increase is 25 percent. It is quite apparent that the further the center of the furnace or tube is from the rigid ends the less support they receive from this source. The first foot of flue or furnace is naturally more benefited than the next foot. This continues this way until the flue or furnace receives no benefit from the rigid ends. In furnaces this is taken care of by rings and joints of several different forms. In boiler flues the rigid ends are not taken into consideration, for the reason that boiler tubes will collapse at one place and the balance of tube be in its true shape.

BRACING.

Above the tubes of tubular boilers is a space in the form of the segment of a circle, and this space has to be supported so that it will be safe for the pressure sought. To support this space braces are placed in the boiler. There are several different styles of braces, and among the several styles are a number of patent braces. Braces may be classified into two kinds, direct and indirect.

DIRECT BRACES.

Direct braces are recommended wherever possible, as the brace is allowed its full value per square inch of area. Direct braces are generally called end to end stays or braces. The pressure allowed per square inch of area depends upon the material and manner of making the braces. Braces with welds are not allowed as great a value as braces without welds. Steel braces are allowed a larger stress per square inch than iron braces, as the tensile strength is greater. Different authorities allow different values, so for this reason no set allowance can be stated that will answer for all cases. Iron braces with welds are generally allowed 6,000 pounds per square inch and steel braces without welds 9,000 pounds per square inch. These values will be assumed in our calculations.

The factor of safety of braces is figured higher than the shell, and this runs from 6 to 8, according to different authorities. Some difficulty is experienced in placing the braces so as to support the segment, with as near an equal tension on each brace as possible. It is quite impossible to so arrange the braces that each one will have the same load. Therefore, we must arrange them so that the pressure will be figured on those which carry the greatest pressure.

RELATIONS OF BRACE TO PLATE.

It is an easy matter to figure the pressure a brace will carry when the area that it will have to support is known.

Rule.—Divide the value for the strength of the brace (expressed in pounds) by the area to be supported and the allowable pressure is found.

While the brace may be good for any stated amount the mode of attaching the brace to the plate will have a bearing on the pressure allowable on the plate, as well as having a bearing on the pitch of the stays. Therefore, we must in placing in stays consider the mode of attaching the braces to the plate. It would be possible to have a few large stays whose area was great enough to stand the pressure, but the pitch of the stays might be so great that the pressure could not be allowed on account of the weakness of the plate.

In Figs. 20 and 21 are shown views of a stay which has been threaded and riveted over in the plate. This is regular staybolt practice, and may be found in use in the smaller tubular boilers. The United States rule has two constants—112 for plates lighter than 7/16 inch and 120 for plates heavier than 7/16 inch. As our head is ½ inch we use the constant 120. We desire to find the area that ½-inch plate with screwed stays riveted over will be good for; that is the maximum pitch which can be used for the stays.

Formula:

A = Constant (United States rule 120 for ½-inch plate).
B = Pressure per square inch.
C = Maximum pitch of stays.
D = Thickness of plate in sixteenths of an inch.

$$\sqrt{\frac{A \times D^2}{B}} = C$$

Substituting values we have:

$$\sqrt{\frac{120 \times 64}{175}} = 6.63'' \text{ pitch, or } 6.63 \times 6.63 = 43.9'' \text{ area.}$$

Having found the pitch of the stays and the area that the stay will have to carry we must now determine the size of the stay. Area × pressure per square inch = total stress upon the stay. Thus $43.9 \times 175 = 7{,}683$ pounds pressure on the plate. Value of stay 6,000 pounds. Thus 7,683 divided by 6,000 = 1.2805 area of stay. We will have to have an area of 1.2805 to support this plate, assuming that the strength of the stay is 6,000 pounds per square inch. This is equal to a fraction less than 1 5/16 inches diameter. These calculations apply to measurements taken at the root of the thread, therefore 1 5/16 inches must not be taken as the diameter of the bolt. Adding on the threads we would for practical purposes use a 1½-inch bolt.

Other rules:

Other authorities allow different values for the strength of a stay-bolt as the constant is increased, and also the unit *one* is added to the thickness of the plate.

Formula:

$$\frac{A \times (D + 1)^2}{B} = C$$

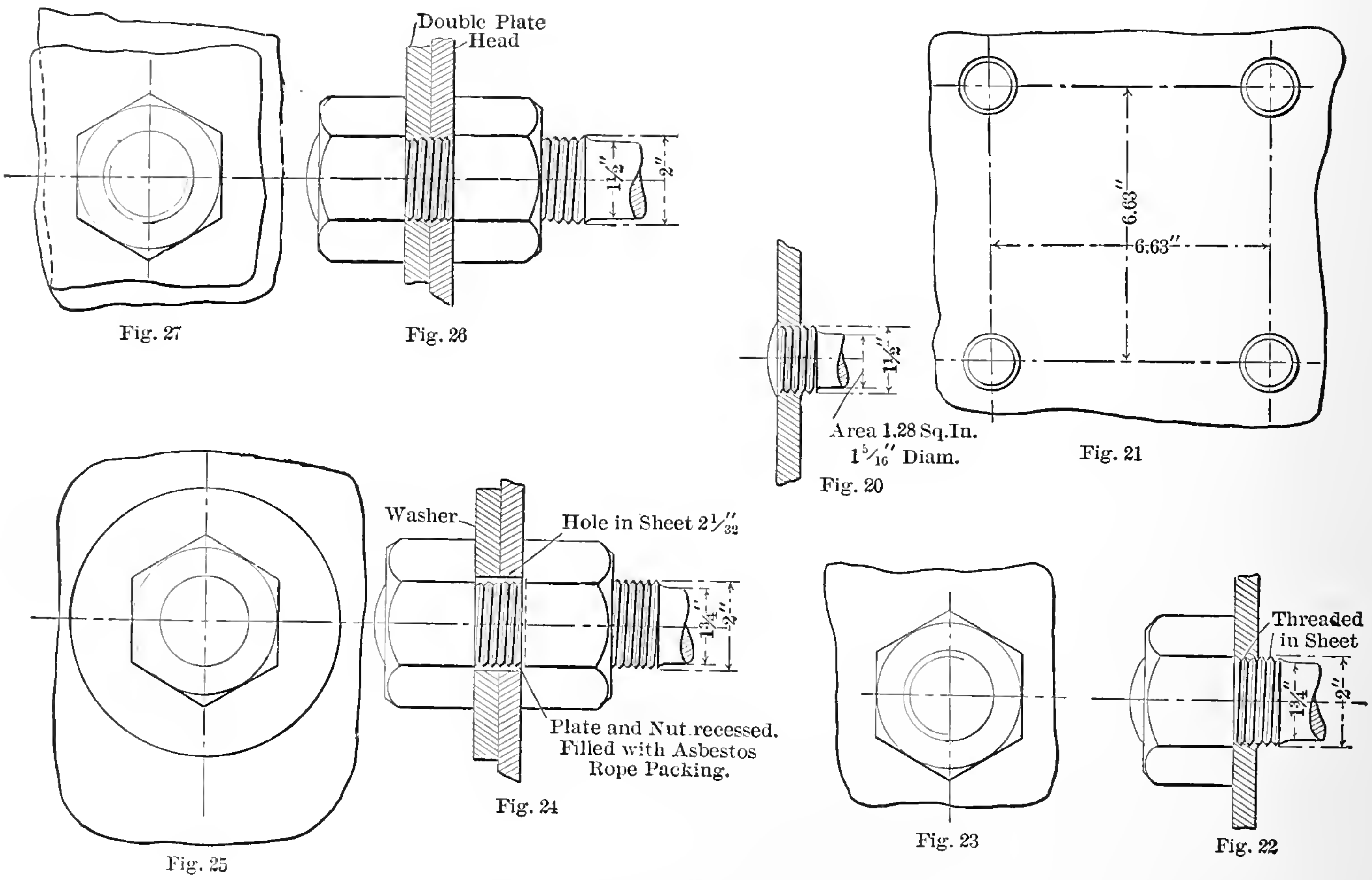
Just to show the difference between the two rules let us assume that the stays are 6-inch pitch.

United States Rule:

$$\frac{120 \times 64}{36} = 213 \text{ pounds pressure.}$$

Figs. 24 and 25 show a brace with nuts inside and outside, but no thread in the sheet. There is also a washer used on the outside. Stays of this character are generally used where there is difficulty in putting them in or in removing them. The hole in the sheet is made large enough to permit the brace to slide through, the inside nut merely acting to keep the joint. The nut and washer on the outside is a substitute for the nut and thread in the sheet as in Figs. 23 and 24.

In large boilers of high pressure it is found necessary when using large braces to increase the thickness of the plate where the braces are attached. It may not be necessary for the entire head to be heavier, as the part held by the flues would be thick enough. Therefore, the part to be increased in thickness would



METHODS OF FASTENING DIRECT STAYS.

British Columbia rule:

$$\frac{125 \times 81}{36} = 281 \text{ pounds pressure.}$$

It will be understood that while there is a difference in the pressure it only applies to the plate. However, the British Columbia rule would permit of a larger stay, and this would then allow greater pressure, while the United States rule will not allow a larger stay, as the plate is the weaker, and nothing would be gained by increasing the size of the stay.

Figs. 20 to 27 inclusive, show four different ways of fastening the braces to the plate. Fig. 21 shows screwed stays riveted over as just worked out in the preceding examples.

Figs. 22 and 23 show the stay screwed into the plate with a nut on the outside. This nut assists in supporting the plate, so a different constant may be used than with Fig. 21.

be that part where the stays are spaced with the greatest pitch.

In order for the plates to withstand the pressure a doubling plate is applied, which increases the thickness of the heads at that portion.

Constants:

Figs. 20 and 21—120.
Figs. 22 and 23—140.
Figs. 24 and 25—140.
Figs. 26 and 27—200.

With the constant 140, using the United States rule, the pitch of stays would be as follows:

$$\sqrt{\frac{140 \times 64}{175}} = 7.15'' \text{ pitch.}$$

When a doubling plate is used it is not the practice to figure the entire thickness, including the doubling plate, but to use

about 80 percent of this. Thus with ½-inch plate and a ½-inch doubling plate .8, or about 13/16 inch would be used in the United States rule as the thickness of the plate.

Assuming 13/16 inch as the thickness we would have for the pitch

$$\sqrt{\frac{200 \times 169}{175}} = 13.9'' \text{ pitch.}$$

These calculations are based upon the fact that all stays have an equal pitch, but this is not always a feasible arrangement in bracing with end to end stays. Some authorities figure on the maximum pitch regardless of the minimum pitch; thus if the stays were 10 by 12-inch pitch they would figure the area at 12 × 12 inches = 144 square inches. Others square the pitch of stays and square the distance between rows of braces, add the two results together, and then divide this sum by two.

A = Pitch of stays in inches.
B = Distance between rows of stays in inches.
C = Area.

$$\frac{A^2 + B^2}{2} = C$$

After the size and strength of the braces have been found, and the proper thickness of plate and pitch of stays have been decided, there is still another matter to consider. It is general practice for the ends of end to end stays to be larger where they are screwed into the sheet. As the smallest diameter must be used as the diameter of the brace, we must be sure to have the diameter at the root of the threads on the upset ends as large or larger than the diameter of the body of the brace. Therefore, the diameter of the upset end depends upon the number of threads per inch.

If United States standard, five threads to the inch are used, the diameter at root of thread would be 1.4902 inches. This is a fraction smaller than the 1½-inch body. Assuming that the brace is good for 9,000 pounds per square inch its total strength would be 13,411.8 pounds.

If twelve threads per inch are used the diameter at the root of the thread would be 1.641 inches and the brace would be good for 14,769 pounds.

Thus, the more threads per inch that are cut the stronger the brace is at the threaded part, since the threads are not as deep.

TO FIND THE AREA OF A SEGMENT.

In this also authorities differ and different results are obtained by using different rules.

Rule 1:

H = Height of the segment in inches.
C = Length of the chord of the segment in inches.
A = Area of the segment in square inches.

Formula:

$$\frac{H^2}{2C} + \frac{2C \times H}{3} = A$$

Assuming that the segment is one-half the head we will figure this rule out. Substituting values we have

$$\frac{27{,}000}{120} + \frac{120 \times 30}{3} = 1{,}425 \text{ square inches.}$$

In order to ascertain just how correct this rule is we will find the area by squaring the diameter and multiplying this product by the constant .7854, which will equal the area for the whole circle. Dividing by 2 will then give the area of the segment.

Example:

$$\frac{60 \times 60 \times .7854}{2} = 1413.72 \text{ square inches.}$$

We find that the two rules are nearly alike, and as the segment to be braced is usually only a small part of the semicircle the difference is yet smaller.

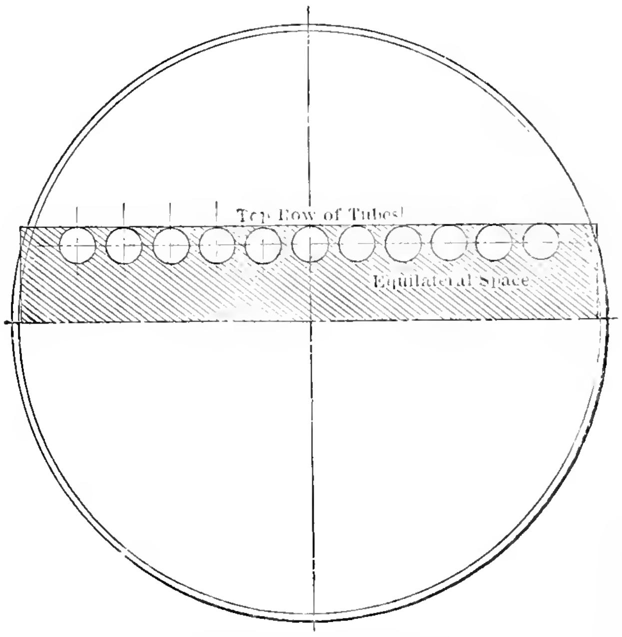


FIG. 28.—SKETCH SKOWING THE EQUIVALENT AREA BRACED BY THE UPPER ROWS OF TUBES.

Another rule is to find the area of the semi-circle and to subtract from it the equilateral space. This does not give the exact result, but nearly all rules are sufficiently accurate for the purpose.

SPECIAL NOTE:—The examples given are taken as if the whole segment were being braced. This is done merely to explain the rules clearly.

INDIRECT BRACES.

Indirect or diagonal braces of different kinds, either of iron or steel, are being extensively used in tubular boiler construction. The iron braces are usually welded, while the steel braces are without welds. The latter have, from practical and scientific tests, proven themselves from 30 to 50 percent stronger than iron-welded braces, due to the lower tensile strength and uncertainty of the weld in iron braces. Steel braces may thus be made lighter and the factor of safety does not need to be so great as with iron braces. Many authorities are allowing on weldless steel braces 9,000 pounds per square inch sectional area.

Diagonal braces are not allowed the full value of the strength of the brace, due to the fact that they do not strike

the head at right angles. Thus, if a brace is allowed 9,000 pounds in direct pull, it would be allowed less if set at 10 degrees, and still less if set at 15 degrees.

If A = Area of brace in square inches.
B = Stress per square inch, net section of brace.
C = Length of line at right angles from the surface to be supported to the end of diagonal brace.
D = Length of diagonal brace.
E = Surface to be supported in square inches.

Then $\dfrac{A \times B \times C}{D \times E}$ = pressure allowed per square inch.

Assuming that the brace is allowed 9,000 pounds per square inch in direct pull, and the length of (C) is 49 inches, with (D)

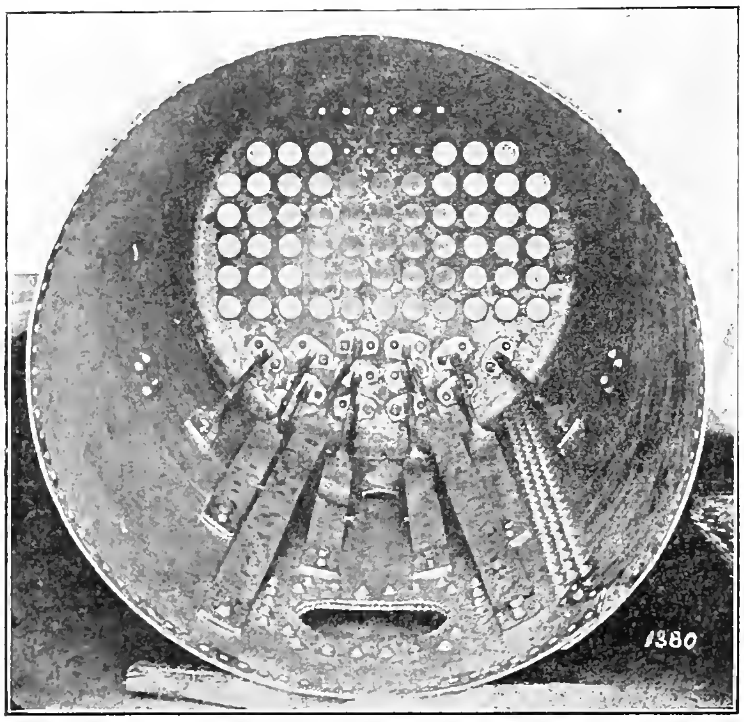


FIG. 29.—BOILER HEAD BRACED WITH DIAGONAL BRACES.

50 inches and the surface to be supported 49 square inches, the pressure allowed would be found by substituting these values in the above equation.

$$\frac{9000 \times 1 \times 49}{49 \times 50} = 180 \text{ pounds.}$$

The photograph, Fig. 29, and the sectional view, Fig. 30 show the manner of fastening diagonal braces, B and D, Fig. 30, representing the distance C in the formula. From the distances A and C and B and D in Fig. 30, the length of the brace is determined.

In Fig. 31 is shown a layout of diagonal braces for a 60-inch boiler head, in which there are sixty-one 3½-inch tubes. Authorities differ in regard to the area to be supported, but nearly all admit that a certain distance from the flange of the head is self-supporting. It is necessary, then, to determine how far from the flange the head may be considered to be self-supporting. First, however, let us determine the amount that will be supported by the top row of flues.

In Fig. 31 we find that the flues are 7⅝ inches above the center line, and the diameter of the flues is 3½ inches. One-half of 3½ is 1¾, which, added to 7⅝, makes from the center line to the top of the flue, 9⅜ inches. The allowance that the flue will support beyond the flue itself is, as explained in previous chapters, a question depending upon the manner and grade of work. It is quite reasonable not to make this allowance too great, as this will cause a much greater stress on the upper row than upon the rest of the flues. Therefore, if we have 1⅛-inch bridge between the flues, we know that each flue is supporting beyond its edge 9-16 inch. From personal observation the writer thinks that the majority are inclined to allow too great a self-supporting distance from the flues. One-half the bridge is, no doubt, a very small allowance, yet it is better to cut the allowance rather than have too much.

The following consideration may throw some light on the reason why that part of the head nearest the flange may go unsupported. The sections of plate between the rivet holes in the flange of the head act practically as a series of braces. With eighty rivets in the circumferential seams we would have

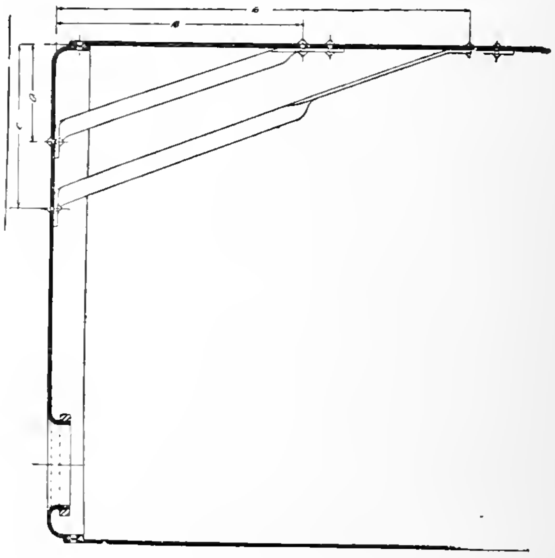


FIG. 30.

about 2.35 inches pitch. This, minus the diameter of the rivet hole (15-16 inch), makes 1.41 inches, giving the net section of plate an area of 1.41 × ½ inch = .705 square inches. As this is subjected to a direct pull, allowing 9,000 pounds stress per square inch, we would have for each section 6,345 pounds. Thus, we see that the net section of plate of the head is actually a very strong brace.

Assuming that the mode of fastening the braces to the head entitles us to use the constant 120, we will find that the maximum allowance for ½-inch plate is

$$\sqrt{\frac{120 \times 64}{175}} = 6.63 \text{ inches, maximum pitch.}$$

The inside diameter of the boiler being 60 inches, the radius will be 30 inches. In order to find the actual distance or height of the segment that we wish to support we will have to make some deductions as follows:

7.625	distance from center line to center of flues.
1.75	distance from center of flue to top of flue.
.56	supported by upper row of flues.
.50	thickness of head.
10.435	inches.

30 — 10.435 = 19.565 inches. Referring to Fig. 31 we find

that we will have three rows of braces. In figuring stays or braces it is assumed that the brace will carry an equal amount on each side. As pointed out, the net section of plate of the head was equal to a brace, so we will assume that the net section of plate will support the head for a distance half way between itself and the next row of braces, but not to exceed the limit as found by the formula. The formula gave 6.63 inches, but to this we add ½ inch, the thickness of the head, and we have 7.13 inches. Thus, we find that from the outside of the head to the nearest row of braces the maximum distance is 7.13 inches.

We then have 19.565 inches, which is to be divided into three and one-half spaces, giving 5.59 inches as the distance between the rows of braces. This is less than the maximum pitch. Distributing the braces in the three rows with a pitch of 8¾ inches we have each brace supporting an area of $8.75 \times 5.6 = 49$ square inches. 49×175 pounds $= 8,575$ pounds total stress per brace.

Some authorities will not allow diagonal braces to have less than 1 square inch sectional area. In order to get the full benefit of their strength very short braces should not be used, since the brace should be as nearly square with the head as possible in order to be allowed the full value of its strength. The less value allowed the brace the greater the net sectional area will have to be. In this case if the braces are not too short they will be large enough if they have 1 square inch sectional area.

FACTOR OF SAFETY.

With 60,000 pounds tensile strength and each brace carrying 8,575 pounds, we have 60,000 divided by 8,575 or 7, as the factor of safety, for the braces.

RIVETS IN THE BRACES.

In dealing with the rivets we have to consider them under two conditions as the rivets in the head will be in tension and the rivets in the shell in shear. Since the strength of these is different it will be necessary to figure both. The practice in some places is to figure only the rivets in shear and make the rivets in tension the same size, paying no attention to their greater strength. Assuming the shearing strength as 42,000 and the tensile strength as 50,000 we will readily see that there is a ratio of 25 to 21. Some allow more for the tensile strength of rivets, but as explained in previous chapters the maximum is considered at 55,000 pounds.

Strength of rivets in shear assuming the shearing strength per square inch as 42,000 pounds:

Diameter, Inches.	Area.	Strength, Pounds.
⅞	.601	25,242
15/16	.69	28,980
1	.7854	32,986.6

Strength of rivets in tension, assuming the tensile strength per square inch as 50,000 pounds:

Diameter, Inches.	Area.	Strength, Pounds.
⅞	.601	30,050
15/16	.69	34,500

In Fig. 31 we find that brace rivets are spaced 4¾ inches by 5.6 inches, thus making $4.75 \times 5.6 = 26.6$ square inches, as the area supported by each rivet $26.6 \times 175 = 4,655$ pounds, stress per rivet.

With ⅞-inch rivets, tensile strength 30,050, the factor of safety will be 30,050 divided by $4,655 = 6.45$. It will be noted that the area alloted to two rivets will exceed the area that the brace will have to carry. In this connection it might be stated that some authorities figure the area from the maximum pitch of rivets or stays, paying no attention to the minimum pitch. Others square both the maximum and minimum pitch, add them togeher and divide the product by two. This, of course, does not give the actual area, but it does serve as a check on unreliable work.

The rivets in the palm of the brace where the brace is attached to the shell will be in single shear. The brace being subjected to 8,575 pounds, the rivets should likewise be figured for this load. Since the factor 7 was used in figuring the brace, it should also be used in figuring the rivets so they will

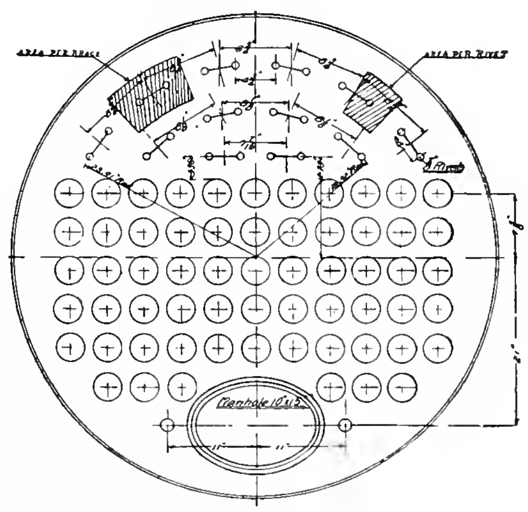


FIG. 31.

not be weaker than the stay. $8,575 \times 7 = 60,025$. Our table shows that this would require us to use two 1-inch rivets. Using the factor 6.45 required for the rivets in tension we find $8,575 \times 6.45 = 55,315.9$. This would require two 15/16-inch rivets.

SIZE OF PALM.

The width of the palm will depend upon its thickness. Assuming that we make the braces out of ⅜-inch steel we will have 1 square inch (the sectional area) divided by $.375 = 2.66$ inches. To this we must add the diameter of the rivet hole. If made of ½-inch steel we would have 1 square inch divided by $.50 = 2$ inches, to which we must add the diameter of the rivet hole.

FORMS OF DIAGONAL BRACES.

In Fig. 32 is shown a diagonal brace fastened to the head with inside and outside nuts. It will be seen that this brace strikes the sheet at an angle and to have the hole a proper fit it would be necessary to drill the hole small and then enlarge it at the angle at which the brace is set. Practical men know that this is a very costly operation and that it does not pay. The general practice is to drill a hole large enough to permit the brace being set at the necessary angle. This makes the hole too large on the sides, and the part of the hole that is not filled with the brace is packed. Bevel washers are

placed on both sides of the head to permit the nuts to be tightened up. This style of brace is generally considered the poorest of bracing.

In Fig. 33 is shown the brace attached to a crowfoot. The crowfoot should be set as indicated by the dotted lines as this gives the brace a proper pull, and not as shown by the solid lines where there is an eccentric loading.

In the use of steel braces the length of the distance *A*, Fig. 35, should not be too great as the braces will have a tendency to straighten out, as shown by the dotted lines. In Fig. 34 we have the palm wider where the rivet holes are placed. There are many who think that the first rivet in Fig. 35 carries more than its share. It is very reasonable to consider that the first rivet is subjected to a prying-off strain, and many contend that both rivets should be subjected to the same conditions. In the case of Fig. 35 we will consider that the rivet is subjected to a prying-off strain. Rivets are either subjected to shear or tension and if the prying-off strain is tension, we find that the strength is increased, because the tensile strength is greater than the shearing strength. Many claim that the palm of the brace should be as shown in Fig. 34, but the general satisfaction given by the brace shown in Fig. 35 indicates that the prying-off strain on the first rivet is not of great consideration. The one main feature is not to have the distance *A*, Fig. 35, too great.

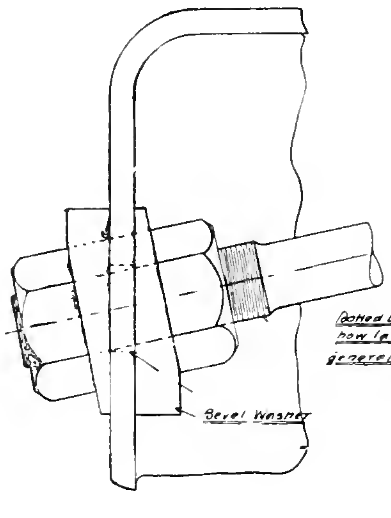


FIG. 32.

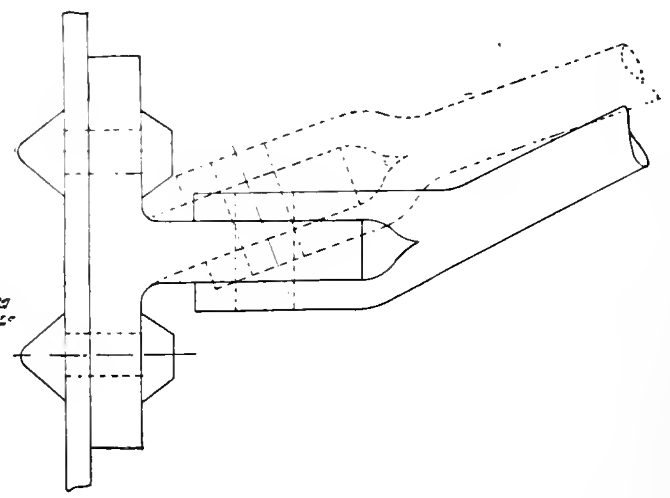


FIG. 33.

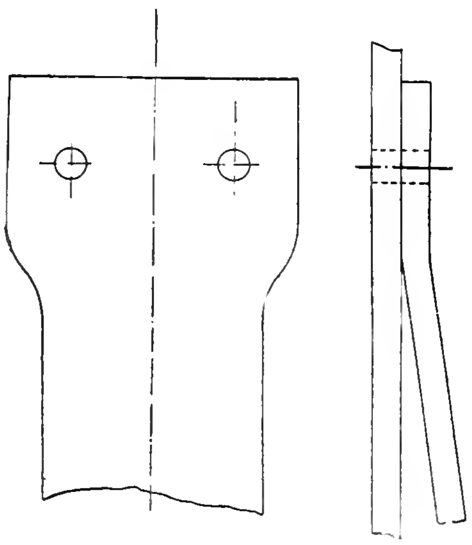


FIG. 34.

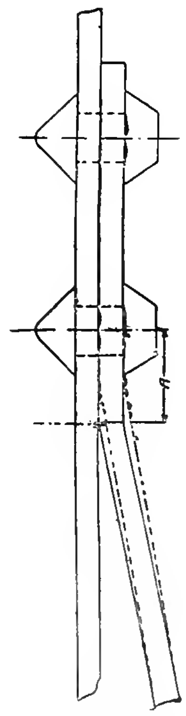


FIG. 35.

Fig. 36 is a view of an eye-brace as used between two angles. To figure out the proper area for both the round and square parts of the brace we must consider the area of the body of the brace. Thus if the body of the brace were 2 inches in diameter, the area would be 3.1416 square inches. To find the size of (*A*) take the square root of 3.1416, which gives 1.79 inches for (*A*). Having found the proportions of *A* and *B*, and assuming that the material of the angles is of the same quality as that of the brace, we must find the values of *F* and *E*. Assuming that *E* is ¾ inch, in order to make (*F*) strong enough, we must multiply *E* by 2 and divide 3.1416 by that product. $2 \times \frac{3}{4} = 1\frac{1}{2}$ inches. 3.1416 divided by $1.5 = 2.094$ inches, value of *F*. *C* should be a fraction greater than *B* to permit the brace to go in and have a little clearance. The proportions of Fig. 36 are figured out for no particular stress per square inch, but merely to show the manner of finding the proper proportions.

BRACE PINS.

There are several different kinds of brace pins. Three, which are in common use, are shown in Fig. 37. The pin shown at *A* is a rough, round bolt, split and bent over. It is a very cheap pin, but hard to put in as well as to remove. At *B* is shown a pin something on the order of the pin *A*, but it has a separate split key. This is not a very satisfactory pin. *C* is a turned pin with nut and cotter key. There is also a recess on the pin so that the threads will not come upon the body of the pin. It is customary in some shops to have the diameter of the threaded part smaller than the body *A*. This pin has much to commend its usage. Many concerns, however, apply simply the rough machine bolt.

STRENGTH OF BRACE PINS.

The strength of brace pins is an unsettled matter. It is assumed that the pin can be treated in the same manner as rivets, that is, they can be so placed as to be in single shear or in double shear. Some authorities do not allow any value

for the pin in double shear and require the area of the pin to be equal to the area of the brace.

The British Columbia rules allow the area of the pin to be 25 percent less than the area of the brace, but at the same time they allow different values on braces. Thus, if a brace made of iron were allowed 6,000 pounds per square inch, it would be satisfactory for the pin to be 25 percent less in area. Should the same style and size of brace be made of steel and not worked in the fire, the brace would be allowed 9,000 pounds per square inch of area. It will be seen that the mere fact that the body of the brace is made of two different metals and by two different methods will give different stresses. Thus they require the same size pin for a stress of 6,000 pounds as they do for 9,000 pounds. This does not seem very consistent.

When the brace pin is in double shear it may be considered as a rivet. Assuming that the shearing strength of the pin is 42,000 pounds per square inch in single shear, the strength in double shear is generally considered as 85 percent more than this, or 42,000 × 1.85 = 77,700 pounds.

What size pin would be needed for a 2-inch diameter brace, allowing 60,000 pounds tensile per square inch for the brace? 2 inches, diameter = 3.1416 square inches, area. 3.1416 × 60,000 = 188,496 pounds, stress. 188,496 divided by 77,700 = 2.43 inches, diameter of pin. It will be seen that in this case the diameter of the pin is larger than the diameter of the brace. If the tensile strength of the brace is less than 60,000, the diameter of the brace pin would, of course, be less.

Taking the same proportions as to strength, let us figure out the pin with a smaller brace, say, 1½ inches diameter.

1½ inches, diameter = 1.767 area. 1.767 × 60,000 = 106,029 pounds.

106,029 divided by 77,700 = 1.365 inches, diameter of pin. It will be seen that with 2 inches diameter of brace, 60,000 pounds tensile strength, 77,700 pounds shearing strength, the diameter of the pin is larger than the diameter of the brace. In the other example, with 1½ inches diameter of brace, but with the same tensile and shearing strength, the diameter of the pin is less than the diameter of the brace.

Braces are allowed different stresses according to the mode of work. Welded braces are not allowed as great a stress per square inch as braces that are weldless. Assuming the tensile strength as 54,000 and allowing 9,000 pounds stress per inch with a weldless brace, the factor of safety is 6, but with a welded brace, allowing only 6,000 pounds stress per inch, the factor is 9. The increased factor is on account of the weld. It will be readily seen that the pin does not lose, whether the brace is welded or not. Therefore, the pin should have a factor of safety regardless of the factor of safety of the brace or material in the brace. A factor of 6 should be ample for brace pins.

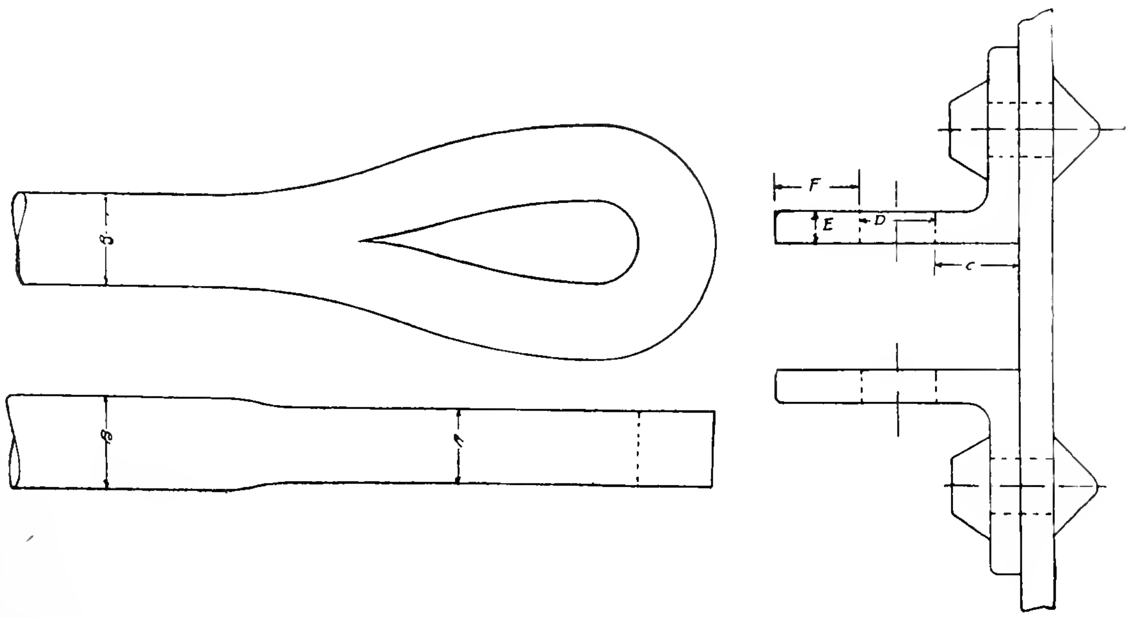
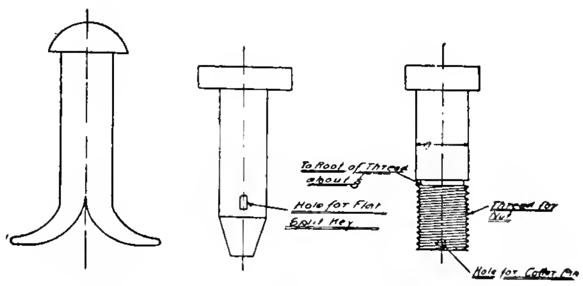


FIG. 36.



A B C

FIG. 37.

With a factor of 6, and allowing 9,000 pounds stress per square inch, what size pin will be needed for a brace 1½ inches diameter, 60,000 pounds tensile strength?

$$1.5 \times 1.5 \times .7854 \times 9{,}000 \div \frac{42{,}000 \times 1.85}{6} = 1.23 \text{ square}$$

inches, area of pin.

$$2\sqrt{\frac{1.23}{3.1416}} = 1.25 \text{ inches, diameter of pin.}$$

While 6 was used as the factor of safety of the pin, it will be seen that the factor for the brace is 60,000 ÷ 9 000 = 6.666.

STEAM DOMES.

The use of steam domes on boilers is fast becoming obsolete, especially where high pressures are used, but their wide use in the earlier days of boiler making makes some consideration of their construction necessary.

Several things must be considered with the dome, viz.,

how it is fastened to the boiler, the style of the vertical seam, the dome head, the bracing, etc. There are in use two general methods of attaching the dome to the shell, one by flanging the dome and the other by having a separate dome base or collar. The latter is generally used in locomotive boiler

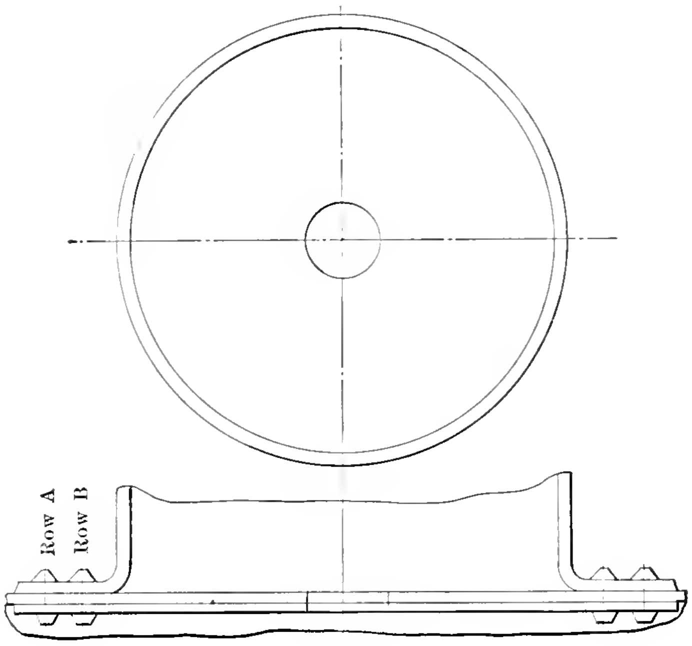


FIG. 38.

construction, mainly on account of the size of hole that has to be cut in the shell sheet in order to put in the dry pipe and fittings. The general practice with most boiler manufacturers is to dish the head so that it will be self-supporting.

There is no set rule to govern the diameter or length of

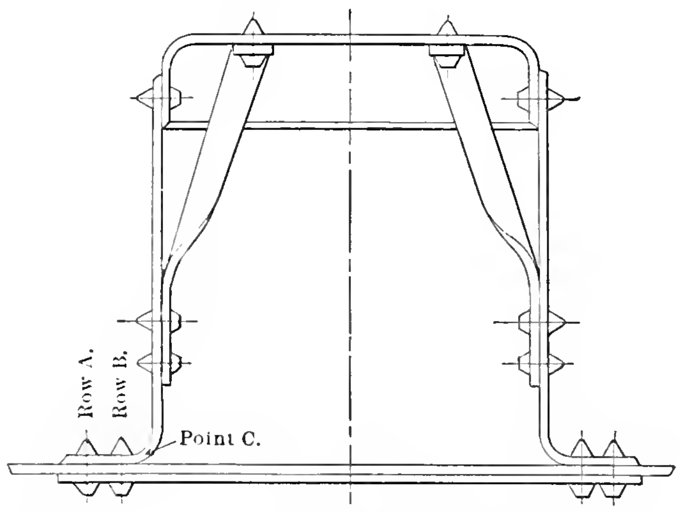


FIG. 40.

the dome, as large and small domes are used indiscriminately, and frequently the same size dome is placed upon several different sized boilers.

NEUTRAL SHEET UNDER DOME.

The neutral sheet under the dome derives its name from the fact that it is subjected to pressure from both sides. There are several methods of providing for the passage of steam through the neutral sheet into the dome. Some punch out a hole in the center one and a half times the diameter of the steam outlet, while others perforate the neutral sheet with a great number of small holes. The latter method is used in order not to weaken the sheet to such an extent as when a large hole is punched. Some claim that placing a dome on a boiler brings an unequal strain upon the shell sheets, due to the fact that the pressure on the dome is borne by the shell

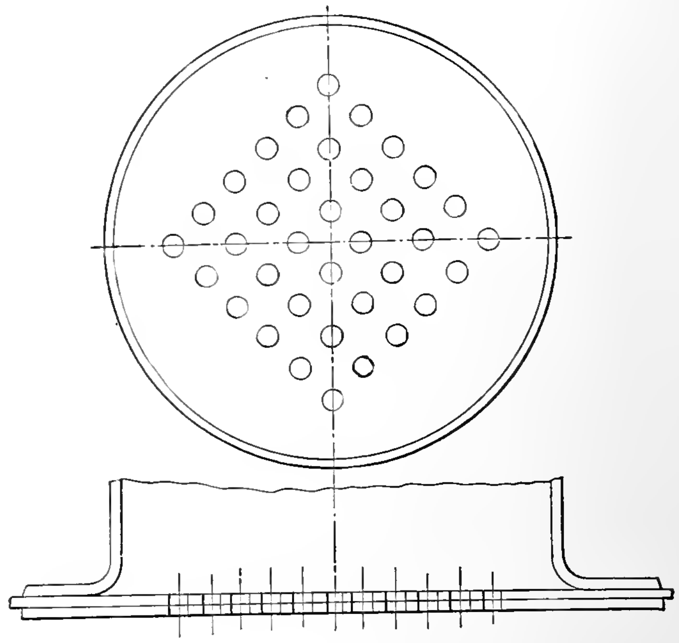


FIG. 39.

sheet where the dome is attached. Authorities differ on this point however. The use of a liner inside underneath the dome is advocated for strength to cover any weakness that

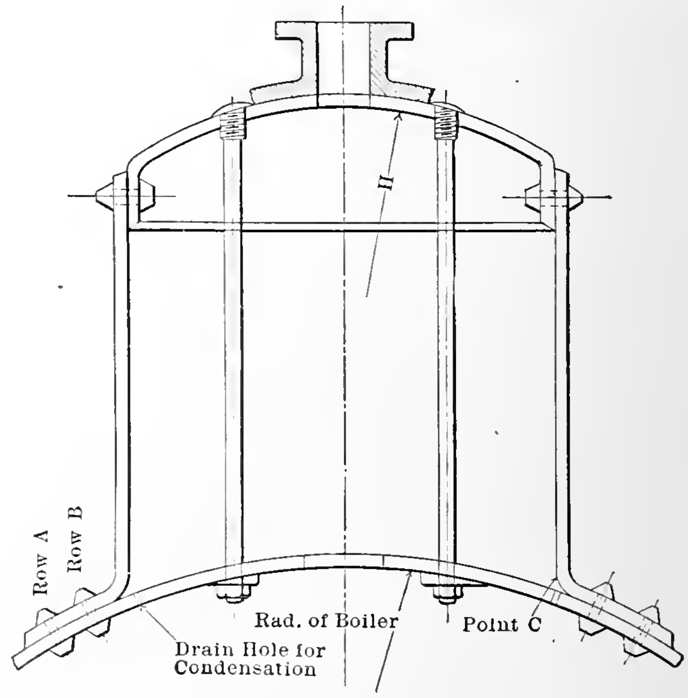


FIG. 41.

might exist from attaching the dome. In Fig. 38 is shown the neutral sheet with a large hole in the center to permit the steam to enter the dome. Fig. 39 shows the neutral sheet perforated.

BRACING THE DOME.

Steam domes may be braced in two ways: First, as shown in Fig. 40 by diagonal braces from the dome head to the dome shell; and, second, as in Fig. 41 by through stays from the dome head to the boiler shell. The diagonal stays in Fig. 40

serve the purpose of bracing the dome head, but do not take any of the load from the joint where the dome is riveted to the boiler shell. On the other hand, the direct braces, as shown in Fig. 41, carry a part of the load which would otherwise come upon the joint between the dome and shell. Assuming the inside diameter of the dome as 26 inches, the area of the dome head will be 530.93 square inches. At 175 pounds steam pressure, there is a stress tending to tear the dome from the shell of $530.39 \times 175 = 92{,}819$ pounds. Assuming that the dome sheet is ⅜ inch thick, and that the joint between the dome and boiler shell is double riveted, so that 70

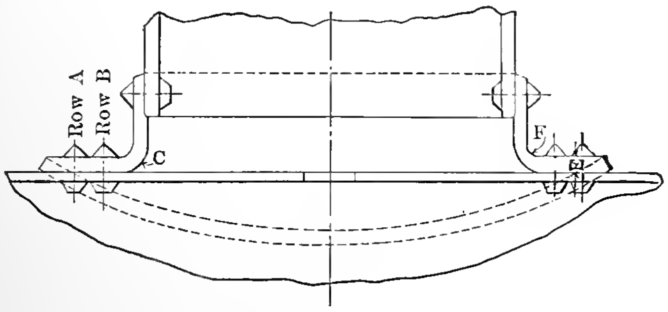


FIG. 42.—DOME COLLAR.

percent efficiency will be obtained, the total stress which the joint will stand will be $60{,}000 \times .375 \times 26.375 \times 3.1416 \times .7 = 1{,}305\,040$ pounds.

$$\frac{1{,}305{,}040}{92{,}819} = 14, \text{ the factor of safety.}$$

A large factor of safety should always be used when computing the strength of this part of the dome, since the sheet is almost always thinned out in the process of flanging; also unknown strains may be set up in the plate due to unequal heating and cooling of the metal, or a weakness may be developed through careless hammering or workmanship. In Fig. 41 the dome head is dished, and therefore does not require bracing. In this case the braces merely protect any weakness at the joints *A*, *B* and *C*.

Fig. 42 shows a dome base or collar. If the base is made out of heavy material there is no danger of any weakness at *A*, *B* or *C*, and the dished head can be used without stays.

DISHED HEADS.

The dishing of the head makes it able to resist pressure, the greater the dish the more the pressure allowed, until the head is hemispherical and then it reaches its limit. It is customary to make the radius of the dished head equal to the diameter of the dome or shell to which it is attached.

The United States rule for convexed heads, as amended January, 1907, is

$$\frac{S \times T}{R} = P$$

Where

P = Pressure allowable per square inch in pounds,

T = Thickness of head in inches,

S = One sixth of the tensile strength,

R = One-half the radius to which the head is bumped.

Add 20 percent when heads are double riveted to the shell and all holes fairly drilled.

Substituting values we have for the head under consideration $\dfrac{10{,}000 \times .375}{13} = 288.5$ pounds. Adding 20 percent for double riveting we have $288.5 \times 1.20 = 346.2$ pounds, pressure allowed.

According to a different rule, if

T_s = Tensile strength,

T = Thickness of plate in inches,

R = Radius to which the head is dished,

F = Factor of safety,

P = Pressure allowed,

$$\text{then } P = \frac{T_s \times T}{R \times F}$$

Referring to previous work we find that our factor with

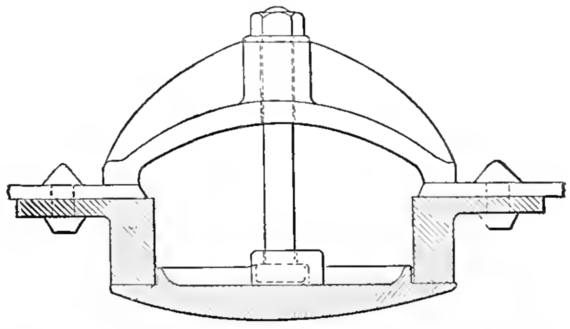


FIG. 43.—MANHOLE, WITH CAST IRON REINFORCING RING.

holes reamed was 4.2. We will therefore use this factor in our example $\dfrac{60{,}000 \times .375}{26 \times 4.2} = 206$ pounds.

It will be seen that neither of these rules figure on the net section of plate at the rivet joint where the head is attached to the shell. The United States rule allows different values for single or double riveting, but does not mention what efficiency is required. We will assume that it is expected that the net section of plate and rivets compare favorably.

Assuming that the head is dished so the weakness is at the net section of plate, we will figure this out to ascertain what factor we will have. Using the constant 1.31 as in previous work, we have $1.31 \times .375 + 1.625 = 2.12$ inches, approximate

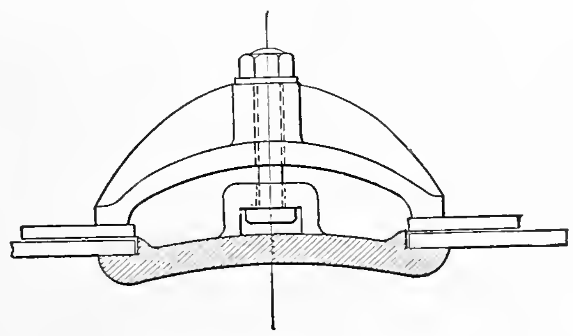


FIG. 44.—MANHOLE REINFORCED WITH STEEL LINER PLATE.

pitch. The circumference corresponding to the mean diameter of the dome (26⅜ inches) is 82.86 inches. Divide this by the approximate pitch for the number of rivets. $82.86 \div 2.12 = 39.1$, say 40 (number of rivets). $82.86 \div 40 = 2.0715$ inches, exact pitch.

Using ¾-inch rivets with 13-16 inch holes we have 2.0715 —

.8125 = 1.259 inches. 1.259 × 60,000 × 40 × .375 = 1,134,000 pounds, strength of net section of plate for single-riveted joint.

$$\frac{1,134,000}{92,912.75} = 12.2 \text{ factor of safety.}$$

The strength of the rivets to resist shearing is 40 × .5185 × 42,000 = 871,080 pounds.

Thus, 871,080 ÷ 92,912.75 = 9.4 factor for the rivets. Thus, a single-riveted joint with a properly dished head will give a large margin of safety for a 26-inch diameter dome.

MANHOLES.

Manholes are placed in boilers of the larger sizes in order to give an entrance to the boiler. The manhole should be

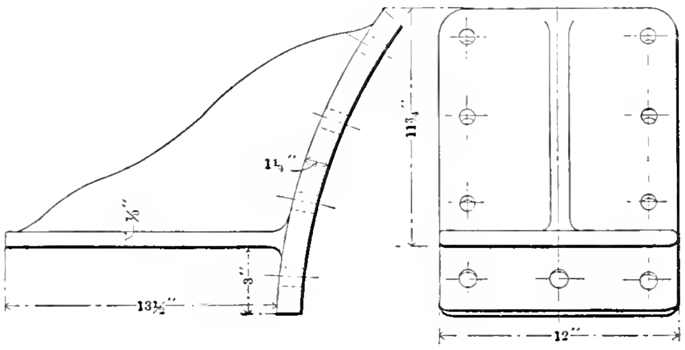


FIG. 45.—CAST IRON WALL BRACKETS.

large enough to permit a man to enter easily, but not larger than is absolutely necessary, as such a cut in the shell must be strongly reinforced in order to preserve the strength of the boiler. This reinforcement is accomplished in several ways. In the older boilers a cast-iron supporting ring, as shown in Fig. 43 was used. Due to the lack of homogeneity, the low tensile strength and blow holes, which are frequently found in iron castings, cast iron has gradually fallen into disuse for any purpose in boiler work. It has been supplanted by steel in this as in almost every other instance. The more

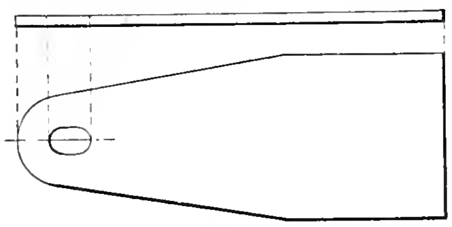


FIG. 46.

modern method of reinforcing a manhole is shown in Fig. 44, where a liner plate is used. The liner may be placed either on the inside or outside or on both sides of the shell. There are a number of patent manhole covers, saddles and yokes on the market to-day which are widely used for this purpose, and might be said to give the best satisfaction, as they are specially designed for a steam-tight joint and maximum strength with a minimum amount of material.

A calculation which must frequently be made is that for finding the size of liner necessary to compensate for the strength lost by cutting the hole. Assume that the manhole is 11 by 16 inches, which is the usual size, although 10 by 15 inches is also frequently used. The minor diameter should run lengthwise of the boiler, therefore we must replace a section of plate 11 inches wide and of the same thickness as the boiler shell. As the boiler shell is 7-16, or .4375 inch thick, this area is 11 × .4375 = 4.8125 square inches. Either the width or thickness of the liner must be decided in order to determine the other dimension. Assume that the liner is 9-16 inch thick, its width will then be $\frac{4.8125}{.562}$ = 8.59 inches. One-half of this will be on each side of the hole, and for the total width the diameter of the rivet holes must be added to this, making, if ¾-inch rivets are used, 10¼ inches for the total width.

Having determined the size of the manhole liner we must now direct our attention to the size and number of rivets necessary in the liner. We found the sectional area of the plate to be 4.8125 and as the steel has a tensile strength of 60,000 pounds per square inch of sectional area the strength

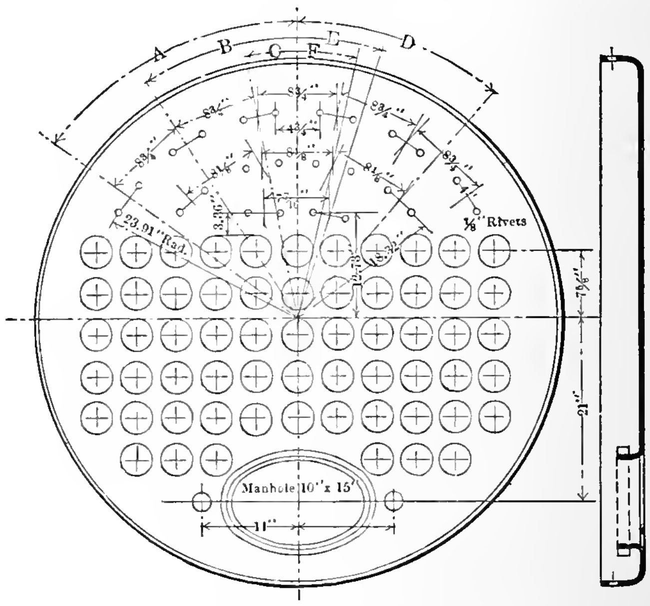


FIG. 47.—LAYOUT OF FLUES AND BRACES.

of this section is 4.8125 × 60,000 = 288,750 pounds. The shearing strength of the rivets being figured at 42,000 pounds per square inch, the strength of one rivet, using 13-16-inch rivets is .5185 (area one rivet) × 42,000 = 21,777 pounds. Thus, 288,750 divided by 21,777 = 13.3 rivets. This would be the number of rivets needed on each side of the center.

With 15-16-inch rivets (area .69), we would have 42,000 × .69 = 28,980 pounds per rivet, and 288,750 divided by 28,980 = 10 rivets on each side of the center.

SUSPENSION OF THE BOILER.

The two most common methods for suspending boilers are by means of hangers and wall brackets. Cast-iron wall brackets, as shown in Fig. 45, were formerly extensively used, but patent steel brackets have replaced them in many instances for the reason that equally strong steel brackets may be made of lighter weight and at a less cost. Also a steel bracket may be riveted to the shell by an hydraulic riveter, thus ensuring tight rivets. The hanger in Fig. 46 is advocated by some authorities to be used on one end of the boiler so that in the event of the boiler getting out of place, due to the sagging of

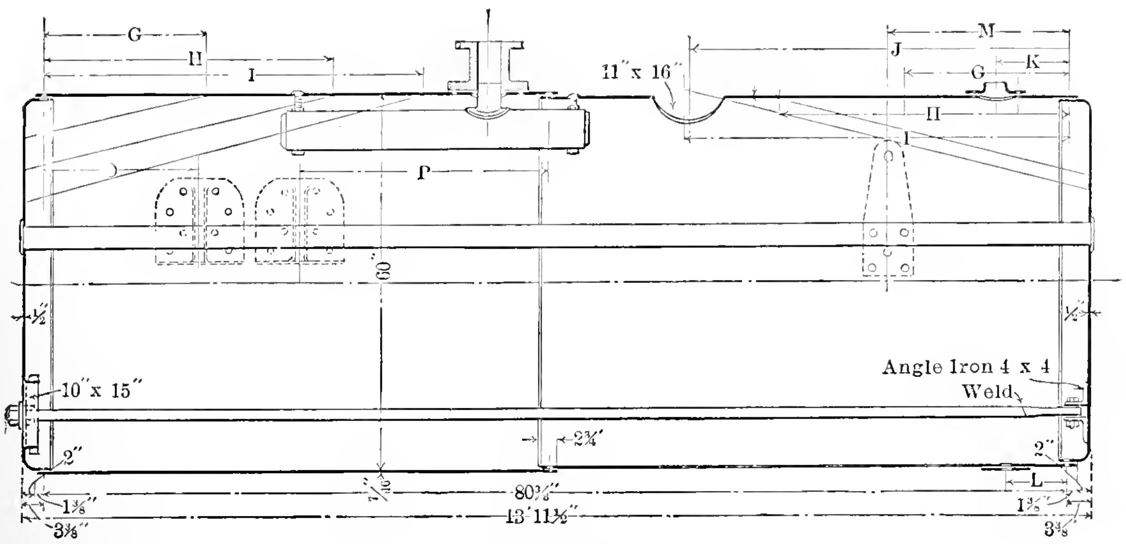


FIG. 48.—SECTIONAL VIEW OF COMPLETED BOILER.

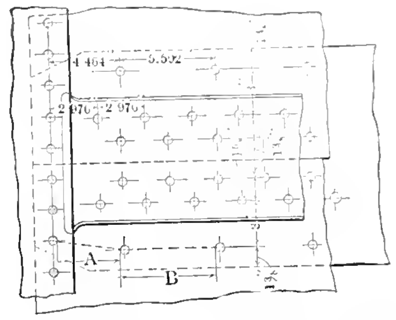


FIG. 49.—DETAIL OF SEAM SHOWN IN FIG. 52.

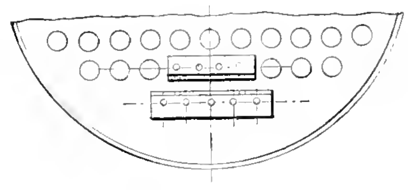


FIG. 50.—DETAIL OF BRACING ON LOWER PART OF BACK HEAD.

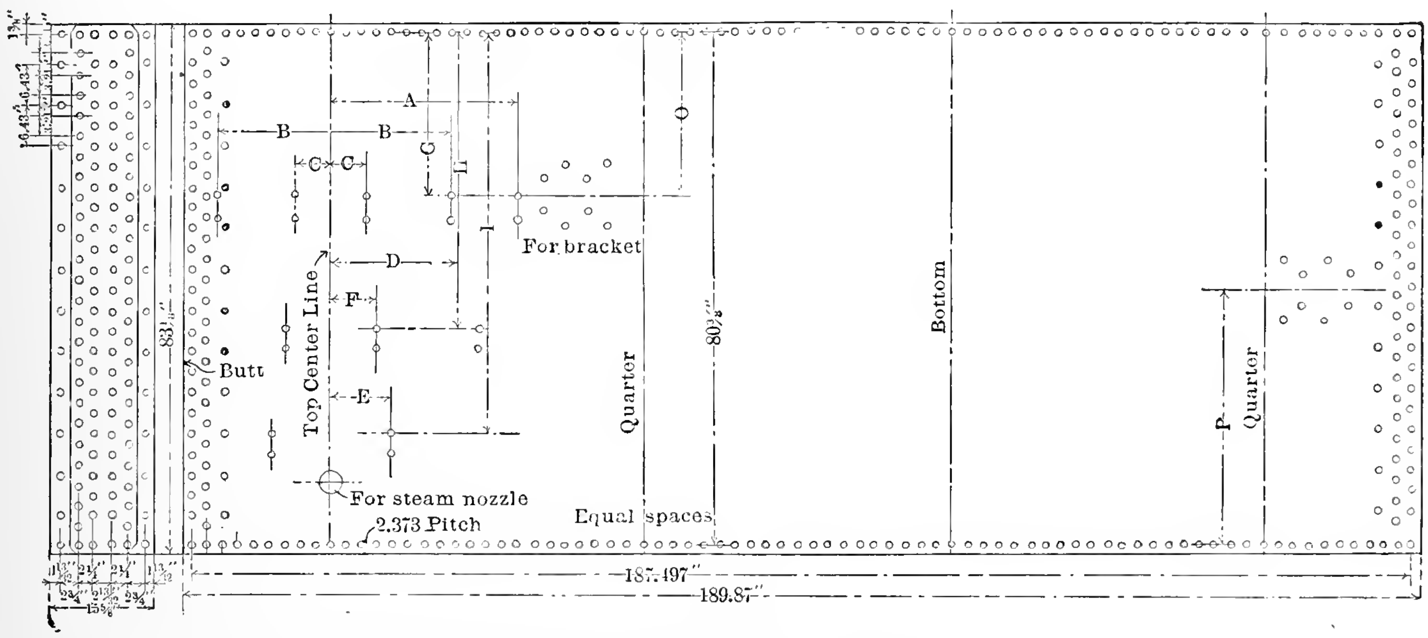


FIG. 51.—LAYOUT OF OUTSIDE COURSE OF SHELL, WITH LONGITUDINAL SEAMS FIGURED ACCORDING TO PRACTICE OF THE HARTFORD INSPECTION AND INSURANCE COMPANY.

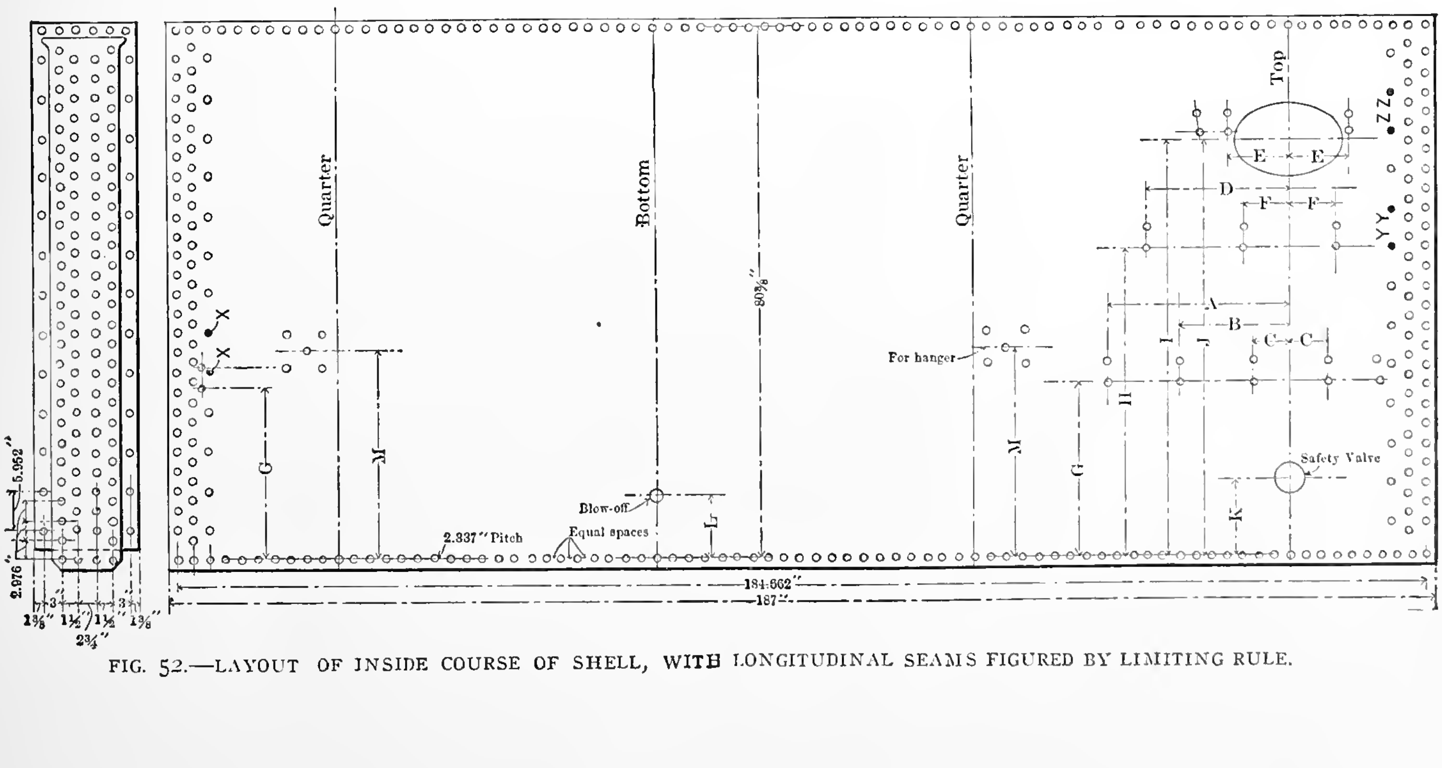


FIG. 52.—LAYOUT OF INSIDE COURSE OF SHELL, WITH LONGITUDINAL SEAMS FIGURED BY LIMITING RULE.

the brick wall, it can be adjusted by merely tightening up the nuts on the U-bolt

The general practice has been with wall brackets to place them staggered on the boiler so that a number of boilers could be placed side by side, and the wall brackets clear each other. Many are to-day advocating the use of wider walls, permitting the brackets to be placed in the same relative position on both sides of the boiler. The distance from the end of the boiler at which the bracket or hanger should be placed is sometimes made one-quarter of the length of the boiler. It is claimed that this will not cause any undue strain on the center circumferential seam. This rule will not apply to a two-course boiler, however, as the quarters at each end have the additional weight of the flue heads, flues, and braces. These weights and also such fittings as the dome, steam nozzles, etc., should be considered in determining the position of the brackets and hangers, rather than any arbitrary rule, such as making the distance from the end of the boiler to the hanger 25 percent of the total length.

NUMBER OF RIVETS IN THE HANGER OR BRACKET.

The rivets in the brackets or hangers will be in single shear, and in order to find the number required it is necessary to know the weight of the boiler and its contents, including all fittings and fixtures. It is the general practice to figure that one-half of the brackets or hangers are to carry the whole weight, as it is considered that at some time the boiler may be displaced from its true setting so that an excessive strain will fall upon one end.

If $A =$ Total weight upon the rivets,
$B =$ Area of one rivet,
$C =$ Shearing strength of one rivet in single shear,
$D =$ Number of rivets for one end,
$F =$ Factor of safety,

$$\text{then } D = \frac{A \times F}{B \times C}$$

Assuming as the total weight for the boiler and details 12 tons or 24,000 pounds, and using ¾-inch rivets and a factor of safety of 12, we have for $D \dfrac{24{,}000 \times 12}{.5185 \times 42{,}000} = 13.2$ or fourteen rivets. This makes seven rivets on each side. It is general practice to have an equal number in a bracket and this would require eight rivets. The adding of the extra rivet will, of course, increase the factor of safety.

THE COMPLETED BOILER.

In the preceding work one boiler has been worked out degree by degree, covering all the vital points of boiler construction for this class of boilers. More might have been written on each and every subject than has been presented, but as the subjects treated are part of the everyday work of a boiler maker, no one should experience a great deal of trouble in applying the rules which have been given to other sizes of boilers. Having figured the size and strength of all the different parts, we are now ready to lay out the completed boiler. Practical considerations will determine for any particular case which of the many possible forms of construction should be used for any individual part. It is sufficient that the boiler maker understands the advantages and disadvantages of the different forms of construction, and is able to figure the theoretical strength of each so that he may judge in a practical way which should be used. With this combination of theoretical and practical knowledge, as outlined in the preceding work, a boiler maker has taken a long step toward a thorough understanding of boiler making.

LAYOUT OF SHEETS, SHOWING METHOD OF LOCATING THE BRACES.

In Fig. 47 is the layout of the flues and the braces. The letters *A, B, C, D, E* and *F* represent the distances from the braces to the top center line of the boiler. Since these distances are measured along the arc, it will be noted that they are obtained by lines drawn from the center of the head to the shell, passing through the center of the braces.

In Figs. 51 and 52 we have the shell sheets as they appear in the flat. The center line of Figs. 51 and 52 is the top of the boiler, hence the distances *A, B, C, D, E* and *F* are the distances as taken from Fig. 47. The letters *G, H, I,* represent the lengths of the braces. Attention is directed to the rivets marked *X, Y* and *Z*. The location of the braces here coincides with the seam. The dotted rivet holes near the rivets marked *X X* indicate where the brace comes. As the seam will not permit of this location the brace is moved to one side. Some place the brace on the outer row of rivets, as shown in Figs. 51 and 52. Attention is also directed to the braces at *E*. In this case the length of the manhole makes it necessary to either shorten the braces or move them to one side. The dotted rivet holes indicate where they should come and the solid lines indicate where they are located.

The letters *M, O, J, P, L* and *K* represent the location of the hangers, brackets, blow-off, manhole and safety nozzle. The circumference, as explained, is generally figured from the mean diameter of the boiler, called the neutral diameter. It is the writer's practice to make a small allowance between the large and small sheets. After ascertaining the circumference of both courses, it has been my practice to make one course about 3-16 inch or ¼ inch shorter or longer than the difference found by figuring the circumferences from both mean diameters. This allowance is generally made, or taken off the small course, as in Fig. 52.

LONGITUDINAL SEAMS.

In Fig. 51 is shown the longitudinal seam worked out according to the practice of the Hartford Insurance Company. In Fig. 52 the longitudinal seam is worked out, the pitch being governed by the limiting rule as stated in previous work. The pitch as worked out by the former is 6.43 inches, which gives 85.4 efficiency (say 85 percent). The pitch as worked out by the limiting rule, as in Fig. 52, gives 5.952 inches with 84 percent efficiency. With the first rule we get a working pressure of 177 pounds, while with the latter we get only 175 pounds pressure.

In Fig. 49 is a detail of the longitudinal seam, shown in Fig.

52. Some question has arisen as to the distance from the circumferential seams to the first rivet. This distance is in this case 4.464 inches, while the length of the net section of plate is 5.592 inches. The arrows in Fig. 49 indicate the direction of force. Naturally the distance A is weaker than B, but in order to break the plate at A, it becomes necessary to shear the rivets in the circumferential seams as marked. Thus, the strength of the rivets of the circumferential seams adjoining A so assist A that it is not a weak place.

Fig. 48 represents the general make-up of the boiler, showing general layout of these parts as indicated in Figs. 51 and 52. In this view two end to end braces are shown, Fig. 50, showing a view of the rear head, with double angles. As already pointed out, welded braces are allowed 6,000 pounds per square inch of sectional area. Therefore, the area under the flues that will be subjected to pressure, multiplied by the pressure, will give the total pounds pressure to be provided for, the rivets in Fig. 50 being in tension. The manner of figuring the braces, brace pins, angles and rivets having been fully brought out in previous work, there is no need of taking this up further. Thus, the blank spaces of the diameter, area and value of the pins will depend upon the area and the pressure.

The Piping and Fittings for a Tubular Boiler.

THE MAIN STEAM OUTLET.

In order to figure comprehensibly on the piping and fittings for any boiler it is obvious that we must have some data as a basis for such calculations. Let us use for the basis of the following calculations an ordinary multi-tubular boiler, such as has been described in the preceding chapter, namely, a 60-inch by 14-foot boiler having 74 3-inch tubes. Having this, and knowing that the ratio of heating surface to grate area in boilers of this type ranges from 30 : 1 to 40 : 1, we can readily figure the grate area. The heating surface must be figured first, and it may be approximately found from the formula:

$$THS = C \times L \times \frac{2}{3} + A + \frac{2}{3} \times a - 2 \times \text{sectional area of tubes.}$$

Where:

THS = total heating surface
C = Circumference of boiler in feet.
L = Length of boiler in feet.
A = Area of surface of tubes in contact with water.
a = Area of tube sheets.

In the problem under consideration this will amount to 916 square feet. Now, taking the mean of the ratios of the heating surface to grate area, namely, 35 to 1, we have for our grate area:

$$\frac{916}{35} = 26.2, \text{ or say, } 27 \text{ square feet.}$$

Having the above data as a basis we will now proceed to find the size of the steam opening.

The size of the steam opening depends, of course, on the amount of water that the boiler will evaporate under normal working conditions. Sometimes this opening is figured according to the size, speed, etc., of the engine for which the steam is generated. As we have not taken any engine into account we will merely observe the method used without applying it to our case. To prevent undue reduction in pressure (there is bound to be some) between the boiler and the engine, due to the frictional resistance opposing the flow of steam, condensation, etc., the velocity of steam through a pipe of moderate

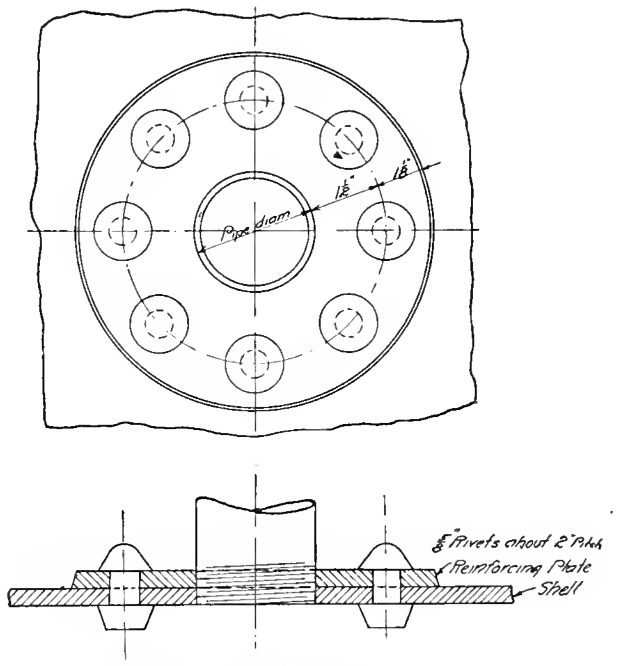


FIG. 1.— SIMPLEST FORM OF REINFORCING PLATE.

length and with several bends should not exceed 85 feet per second, or 5,100 feet per minute. Then the area of the steam pipe may be found from the formula:

$$A = \frac{a \times s}{5{,}100}$$

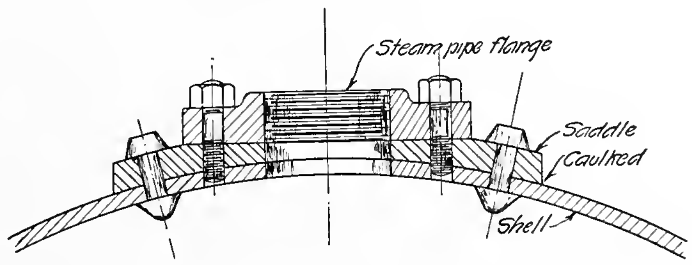


FIG. 2.—SADDLE BENT TO FIT SHELL AND PLANED TO RECEIVE PIPE FLANGE.

Where: A = Sectional area of steam pipe in square inches.
a = Area of piston in square inches.
s = Piston speed, feet per minute.

Another formula which will be applicable in our case is

$$A = \frac{N \times V \times 144}{V_s \times 62.42}$$

Where: A = Sectional area of main steam pipe in square inches.
N = Number of pounds of water evaporated per minute.
V = Relative volume of steam.
V_s = Velocity of steam, feet per minute.

NOTE:—The relative volume of steam at any pressure is the

volume of 1 pound of steam at that pressure as compared with the volume of 1 pound of distilled water at the temperature of maximum density.

We have seen what V_s should be, namely, 5,100 feet per minute, and the value of V may be found from any table of the properties of saturated steam, so it only remains for us to determine N.

In multi-tubular boilers the amount of coal burned per square foot of grate surface varies from 12 to 24 pounds per hour, mean 18 pounds. The amount of water evaporated per

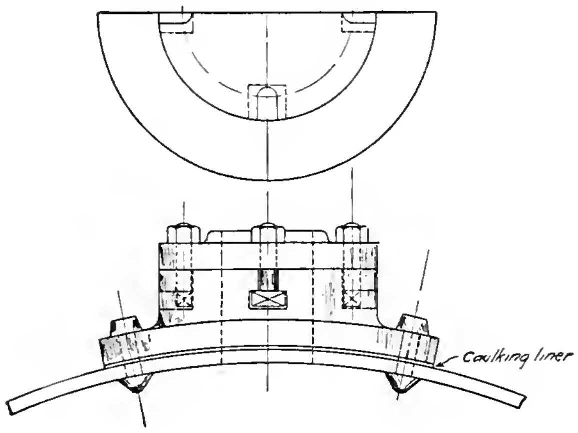


FIG. 3.—CAST STEEL SADDLE FITTED WITH TEE BOLTS.

pound of coal varies from 8 to 12 pounds, the mean being 10 pounds. We have found the grate surface to be 27 square feet, therefore we can figure on $10 \times 18 \times 27 = 4{,}860$ pounds of water per hour, or 81 pounds per minute. Hence, substituting these figures in our formula we have

$$A = \frac{81 \times 169.3 \times 144}{5{,}100 \times 62.42} = 6.21 \text{ square inches,}$$

169.3 being the relative volume of steam at 150 pounds pressure.

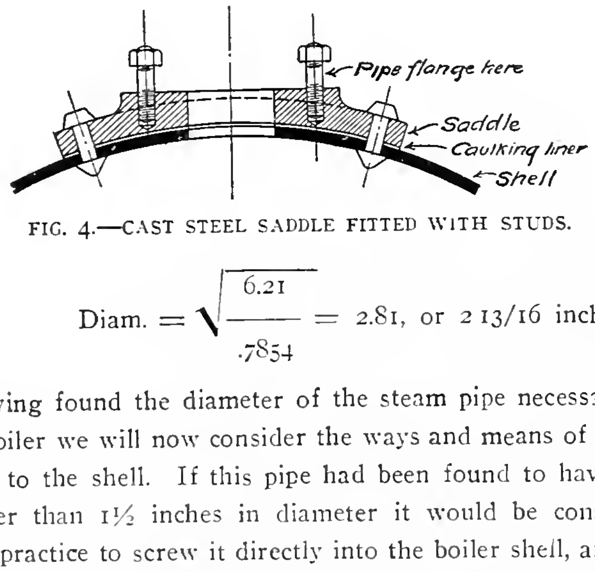


FIG. 4.—CAST STEEL SADDLE FITTED WITH STUDS.

$$\text{Diam.} = \sqrt{\frac{6.21}{.7854}} = 2.81, \text{ or } 2\ 13/16 \text{ inches.}$$

Having found the diameter of the steam pipe necessary for our boiler we will now consider the ways and means of fastening it to the shell. If this pipe had been found to have been smaller than 1½ inches in diameter it would be considered good practice to screw it directly into the boiler shell, and if it had been between 1½ and 2½ inches in diameter we could also fasten it direct to the shell, but the hole would be better if reinforced with a piece of plate riveted on so that the thread would have enough metal to secure a good hold. Fig. 1 shows such a reinforced hole.

As the diameter of our pipe is 2 13/16 inches we must attach it to the boiler by means of flanges, and there must therefore be some sort of seating block or saddle to overcome the cylindrical shape, and provide a flat surface for the flange of the pipe. There are several ways of providing this flat surface. First, we could take a thick piece of boiler plate, and after bending it to fit the boiler have it planed off on the convex side until it presented a flat surface equal in diameter to the diameter of the flange on our pipe. This piece is then riveted to the boiler and studs furnished for the pipe flange (see Fig. 2). This saddle is sometimes made of cast iron or cast steel, adapted either to the use of bolts with tee heads, as in Fig. 3, or with studs as in Fig. 4. These castings must be provided with a calking liner of thin steel or sheet iron placed between the casting and the boiler shell, so that the joint may be made tight by calking, as the castings themselves cannot be calked.

Instead of a saddle we may use what is commonly known as a nozzle for attaching the steam pipe to the shell. One advantage gained is that the diameter of the rivet circle is smaller, necessitating fewer rivets, and then bolts may be used instead of studs, which is very advantageous. Such a nozzle is shown in Fig. 5. These may be made of cast iron, cast steel or brass. The latter metal is generally specified for marine boilers where a very high class of work is demanded.

The thickness of the metal in a cast iron steam nozzle to suit our case is given by the formula:

$$T = \frac{D \times P}{4{,}000} + .5$$

Where: T = Thickness of metal in inches.
P = Pressure in pounds per square inch.
D = Internal diameter of nozzle in inches.

Substituting our figures we have

$$T = \frac{2.81 \times 150}{4{,}000} + .5 = .6054, \text{ say, } 5/8 \text{ inch.}$$

The finished thickness of the upper flange may be 1.3 times this thickness:

$$1.3 \times .6054 = .787, \text{ say, } 13/16 \text{ inch.}$$

On account of the lower flange being riveted to the shell and thus being subjected to the vibratory strain of driving the rivets, and the great strain due to the contraction of the rivet, it is well to add from 40 to 50 percent to the flange thickness thus found up to 1½ inches. Then our bottom flange becomes

$$.787 + .394 = 1.181, \text{ say, } 1\tfrac{1}{8} \text{ inches.}$$

THE SAFETY VALVE.

The next fixture of the boiler to consider is the safety valve. The types of safety valves in use may be classed under the following heads: Lever, dead weight and spring loaded valves. Lever safety valves are frequently used on stationary boilers, but they have the objection that the friction of the joints cause an extra resistance, and consequently an increase of steam pressure when the valve is rising. To reduce this friction to a minimum the bearing of the fulcrum on the fulcrum link and other bearings should be of the knife edge type. Dead weight valves are also used on stationary boilers. This type of valve is efficient and sensitive, and it is difficult to tamper with it by the addition of further weights than the valve is designed to carry. Spring-loaded valves are suitably

adapted to all types of boilers. They are of two kinds: one in which the spring is not exposed to the action of the steam when working, and the other in which the spring is exposed to the action of the steam when working. It is advisable to furnish all safety valves with a lifting device by which the valve may be raised from its seat from time to time, so as to prevent the moving parts from becoming corroded and sticking, thus preventing the free action of the valve in performing its duty, which is to relieve the pressure in the boiler when it exceeds that at which the boiler is designed to work.

The safety valve should have a large area, in order to provide a large opening, for the escape of steam, with a small lift of the valve, otherwise the pressure of the steam may considerably exceed the pressure under which the valve began to rise before the valve lifts sufficiently to permit the free escape of the steam. The valve should not allow the pressure of the steam to rise above a fixed limit, and when this limit is reached it should discharge the steam so rapidly that very little or no

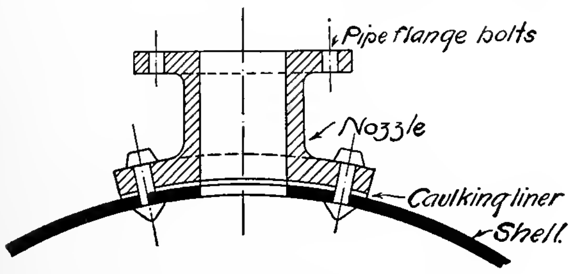


FIG. 5.—STEAM NOZZLE.

increase in the pressure of the steam can take place, no matter how rapidly the steam may be generated.

The area for the safety valve of a boiler may be determined from the grate area by the formula:

$$a = \frac{A \times 4}{\sqrt{P}}$$

Where: a = Area of valve in square inches.
P = Working pressure in pounds per square inch.
A = Area grate surface in square feet.

Substituting our figures we have

$$a = \frac{27 \times 4}{\sqrt{150}} = \frac{108}{12.24} = 8.825 \text{ square inches.}$$

$$\text{Diam.} = \sqrt{\frac{8.825}{.7854}} = 3.35, \text{ say, } 3\tfrac{1}{2} \text{ inches.}$$

From the evaporative power of the boiler the area of safety valve may be found approximately by the formula

$$a = \frac{E}{40 \times \sqrt{P}}$$

Where: E = Evaporating capacity of boiler in pounds per hour.
P = Working pressure.

Substituting we have

$$a = \frac{4{,}860}{40 \times \sqrt{150}} = 9.920 \text{ square inches.}$$

Whence diameter = 3.55, say, 3½ inches.

Another formula for the area of safety valves used by the British Board of Trade is

$$a = \frac{37.5 \times A}{G\,p}$$

Where: a = Area safety valve in square inches.
A = Grate area in square feet.
$G\,p$ = Absolute pressure = boiler pressure + 14.7

In our case

$$a = \frac{37.5 \times 27}{164.7} = 6.14 \text{ square inches.}$$

Whence diam. = 2.80 inches, say, 3 inches.

The weight of steam that will escape in an hour through a

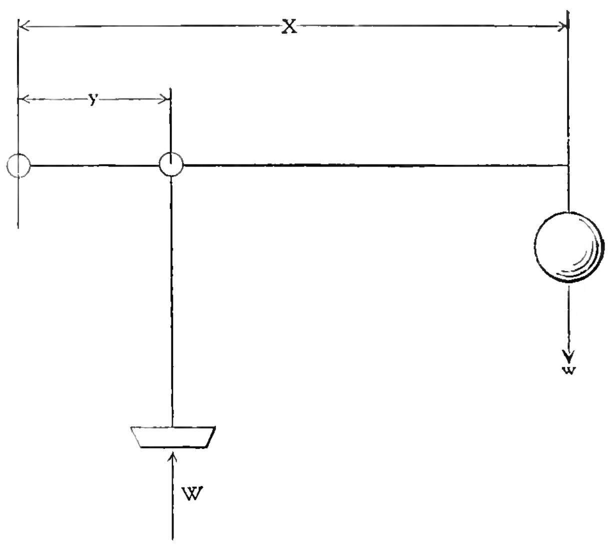


FIG. 6.

square-edged opening, like that occurring in a safety valve, may be approximately determined from the formula:

$$W = \frac{A\,P}{.023}$$

Where: W = Weight of steam in pounds discharged per hour per square inch of opening.
$A\,P$ = Absolute pressure of steam in pounds per square inch.

The weight on the lever of a lever and weight valve is easily found by finding the total pressure on the valve, due to the pressure at which the valve is to open. This found, the principal of the lever and fulcrum is applied (Fig. 6).

Let W = Load on valve due to steam pressure.
w = Weight of ball.
x = Distance of ball from fulcrum in inches.
y = Distance of point of contact of valve spindle with lever from fulcrum.

then $x \times w = W \times y$

or $$w = \frac{W \times y}{x}$$

Having found W and decided on the distances x and y, the weight of ball may be found by substituting these values in the formula. In dead-weight valves the weight of the valve and dead-weights is, of course, equal to the total pressure on the

valve, which is equal to the area of the valve multiplied by the pressure at which the valve is to open.

In spring-loaded valves the size of the steel of which the spring is to be made may be found from the formula

$$d = \sqrt[3]{\frac{S \times D}{C}}$$

Where: S = Load on springs in pounds.
D = Diameter of spring in inches from center to center of wire.
d = The diameter, or side of square, of wire in inches.
C = 8,000 for round steel, 11,000 for square steel.

The pressure or load on a spring-loaded safety valve may be found by the formula

$$\frac{d^3 \times 2}{D} = S$$

Where: d = Diameter of wire in sixteenths of an inch.
D = Diameter of spring in inches from center to center of wire.
S = Load on spring in pounds.

The Dry Pipe.

In connection with the steam outlet of a boiler there is usually some arrangement made whereby the steam drawn from it is freed as far as possible from the particles of water suspended therein, which would cause trouble if allowed to get to the engine. There is, of course, the "separator," which is usually placed in the steam line close to the engine, but there is also provision made in the boiler itself to separate the steam from the water.

In Fig. 7 is shown a very simple and usually effective way of doing this. This separator, or "dry pipe," as it is called, should be for the boiler under consideration (60 inches by 14 feet) about 5 feet long, 8 inches wide and 6 inches deep. On the two sides are punched rows of holes from 3/8 to 1/2 inch in diameter. The area of these holes should aggregate at least two to three times the area of the steam outlet, so that the passage of the steam through them will not be hurried nor restricted. The material used is No. 12 or No. 14 gage sheet iron, and it is held in place against the top of the shell by three or four rivets on either side. Some makers put separating washers on these rivets, thereby leaving a narrow space around the top between the shell and the dry pipe.

The writer knows of one instance at least where the boiler with a dry pipe made with an open strip around the top gave a good deal of trouble by priming. The steam space was rather limited, and it was suggested that the water was drawn by the steam (aided by capillary action) around the shell through this opening into the steam pipe. Whether this was the case or not, this dry pipe was removed and one similar to the one shown in Fig. 8 was put in. The boiler, since then, has given no trouble, by priming, so it would appear there was some truth in the suggestion as made above.

The ends do not have to be absolutely water tight, nor the work expensively careful, the main idea being to form a series of corners that the steam must turn, thereby throwing out the suspended particles of moisture by centrifugal force.

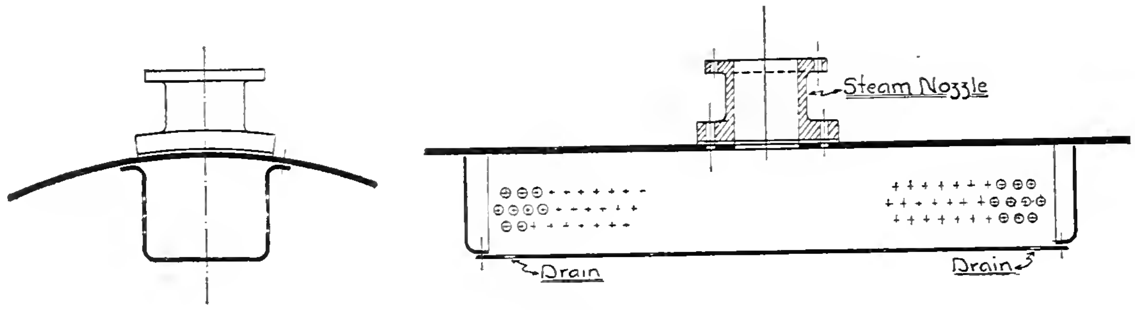


FIG. 7.—BOX FORM OF DRY PIPE.

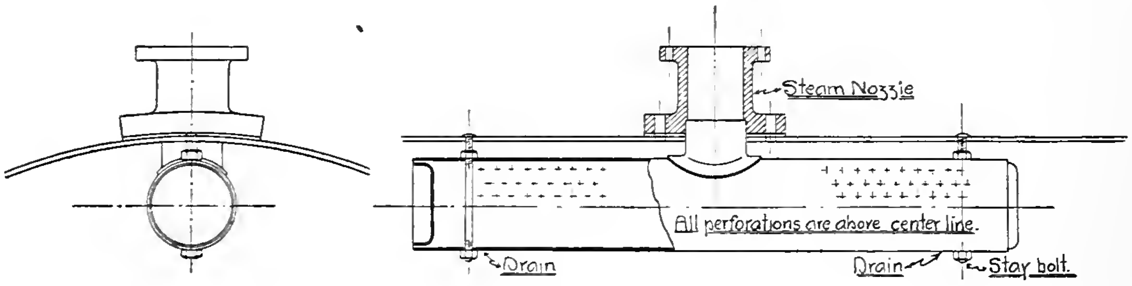


FIG. 8.—CYLINDRICAL DRY PIPE.

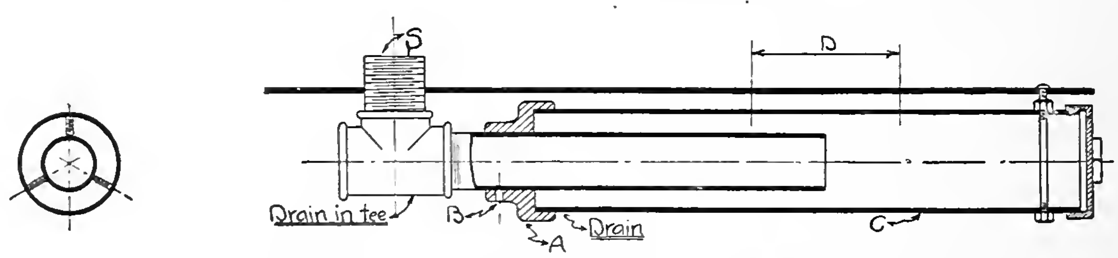


FIG. 9.—DRY PIPE IN WHICH THE MAIN STEAM PIPE IS COMPLETELY SURROUNDED.

A more elaborate form of dry pipe is shown in Fig. 9. *S* is the steam pipe, a branch of which passes through the casting *A*, which fits snugly about it and is held in place by the set screw *B*. *C* is the dry pipe proper, and is about two or three sizes larger than the steam pipe. This is threaded on each end, one end being furnished with a plug or cover and the other screwed into the casting over the steam pipe. The pipe *C* is perforated as usual above its center line, but there are no holes for some distance on either side of the end of the steam pipe, as shown by space *D*. The ends of this pipe are stayed to the

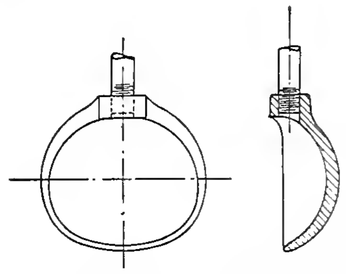


FIG. 10.—CUP-SHAPED SCUM BLOW-OFF.

boiler with stay-bolts, as shown, and when the pipe *S* is of considerable length this pipe is centered in the dry pipe by means of two or three set screws, as shown in the sectional view at the left of Fig. 9.

These separators or dry pipes are largely responsible for the modern practice of making boilers without domes, as they perform practically the same office and are considerably less expensive to make.

The Blow-Off.

As the water fed to boilers is always more or less impure, and as there is also a precipitation of solid matter on account of the high temperature of the water in the boiler, there must be some arrangement made for cleaning the boilers when in ser-

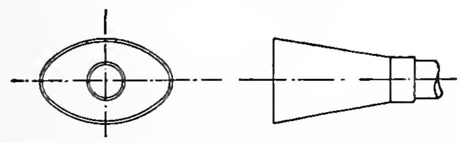


FIG. 11.—FUNNEL-SHAPED SCUM BLOW-OFF.

vice and for getting rid of these impurities or solid matter. This function is performed by the "blow-off." There should be two furnished, one to take care of the solid matter which sinks and one to take care of the lighter substances which float on the surface. The former is placed at the bottom of the boiler near the back head (which is always set an inch or so lower than the front), and the other one in the back of the boiler, either at or a little below the water line. The openings should be ample, and pipes leading from them furnished with a special valve, which is generally of the plug type, as there is less liability of valves of this type becoming clogged by the passage of sediment through them. The pipes should lead as directly as possible to the place of discharge with the least possible number of bends in them.

The scum cock, as the top blow-off is usually called, may have an area equal to the evaporative power of the boiler in pounds of water per hour $\times$ .00053. The boiler end of the scum blow-off pipe is usually funnel or cup-shaped, as shown in Figs. 10 and 11.

The bottom blow-off should have a little larger area than the upper one, and it is found by multiplying the evaporative power of the boiler in pounds of water per hour by .00082.

The blow-off cocks are preferably of gun metal or similar metal, and if made of cast iron they should have linings of this metal for the plugs to work in, the plugs themselves being of the same metal as the linings.

The taper of the plugs in scum cocks should be about 1 in 8. For blow-off cocks up to 90 pounds steam pressure 1 in 6; up to 180 pounds steam pressure 1 in 8; for higher pressures 1 in 10. As blow-off cocks are liable to stick fast they should

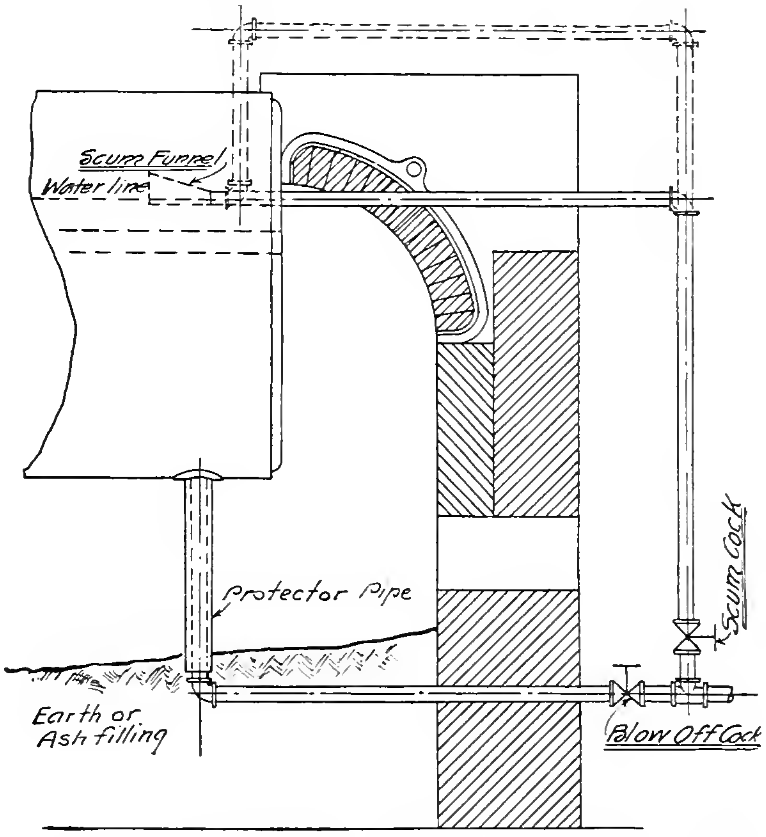


FIG. 12.—ARRANGEMENT OF PIPING FOR SCUM AND BOTTOM BLOW-OFFS.

be opened regularly, and the plugs should be kept clean and the stuffing boxes always adjusted.

Fig. 12 shows the relative position of the scum and blow-off cocks leading to the same discharge point. Although it is better to have the scum blow-off pipe coming out directly, as shown by the full lines, if the back arches or brick work interfere, it may be brought out, as shown by the dotted lines, without much loss of efficiency. Sometimes the system is arranged as shown in Fig. 13, in which, if the cocks *A* and *B* are opened and *C* closed there will be a circulation through the pipes tending to keep them clean. At the same time either one can be used independently of the other if so desired.

The Injector.

Now, we will consider the ways of replenishing the water in the boiler to make up for the steam used. We may either use an "injector" or boiler-feed pump or both. Generally both are supplied with large boilers or a battery of boilers, so that one can be used as an auxiliary for the other, or when the other is being repaired. The principle on which the injector acts depends on the fact that steam rushing through a narrow passage creates a partial vacuum and draws the water in with it, imparting a sufficient momentum to the water to overcome the

pressure due to the steam in the boiler. The water is passed into the boiler through a pipe supplied with a check valve and shut-off valve. The check valve opens towards the boiler by the water pressure, but as soon as the steam pressure is greater than the water pressure the valve shuts, thus stopping the steam from escaping, or the water from returning. Fig. 14 shows an outline of a common flap-check valve. The shut-off valve is placed between the check valve and the boiler, so that

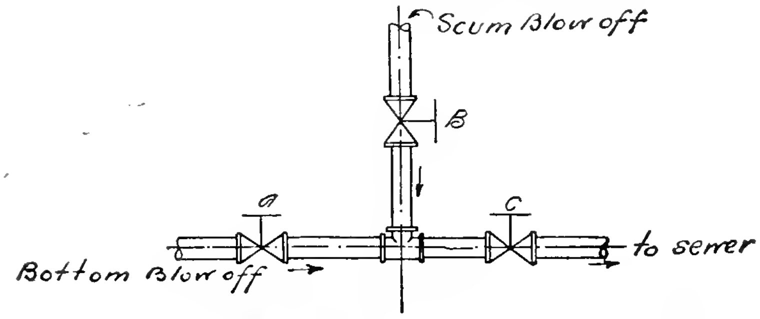


FIG. 13.—ARRANGEMENT OF VALVES IN BLOW-OFF PIPING.

in the case of break-down or the check needing repair the system can be completely shut off from boiler pressure.

The action of feeding water into a boiler tends to lower the temperature of the water already in the boiler, and thus cause an extravagant use of fuel to keep the pressure normal on account of the time it takes to raise the temperature of the feed to the temperature of the water in the boiler. Thus it will be seen that rapid or intermittent injection of feed water is not so efficient as a slower, regular movement, and that the tem-

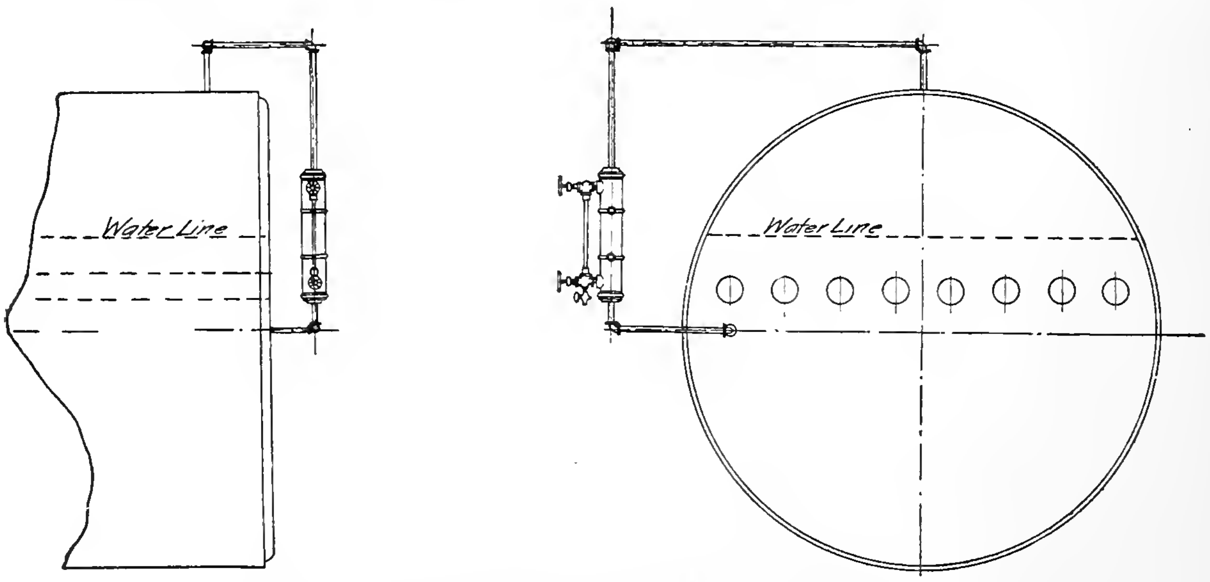


FIG. 15.—LOCATION OF WATER COLUMN AND CONNECTIONS.

perature of the feed water should be as high as possible before entering the boiler. In using an injector the steam that operates it passes with the water into the boiler, and thus warms it, which is one advantage of the injector over a pump. To get warm water into a boiler by using a pump the water must be passed through a heater on its way from the pump to the boiler.

The Feed Pipe.

The feed water should not enter the boiler at the bottom, as this tends to increase the amount of "dead water" at that point. The best place on a multi-tubular boiler, such as the one we are considering, is near the back end, about 4 or 5 inches below the water line. If it enters above the water line the steam being quicker in action than the water in the boiler, will start back quicker after the momentum of the incoming water is lessened, and will cause the check valve to close violently, or in engine room parlance, "will pound the checks to pieces in no time."

To aid the water in the boiler in raising the temperature of the feed, the feed water should be dispersed inside the boiler

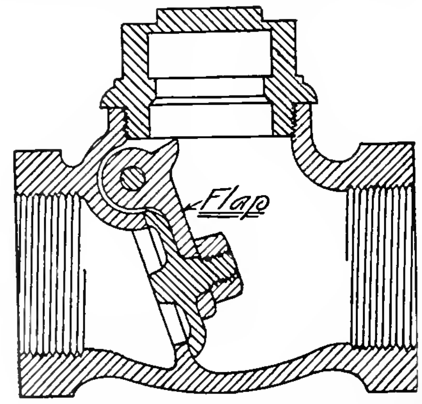


FIG. 14.—DETAILS OF CHECK VALVE.

in as small quantities as possible, and to accomplish this some makers run the feed-water pipe a considerable distance into the boiler, and have the end connected to a branch full of small perforations, the aggregate area of which should be at least twice that of the feed pipe, to allow a considerable margin against some of them becoming clogged up.

Another way is to lead the feed into a box having a perforated cover (below the water line), which may be removed from time to time and cleaned. This is probably the best way, as the box acts as a "catch all" for sediment entering the boiler with the feed water.

The Feed-Water Pump.

As the feed pump is not a direct connection of the boiler (although an important adjunct to the boiler room), I will merely give a few of the principal features, such as size, speed, etc.

The size of the plunger of a boiler-feed pump may be approximately determined by the following formula:

$$A = E \times .002.$$

Where A = Area of plunger in inches.

E = Evaporative capacity of the boiler in pounds of water per hour.

The length of stroke should be from one to one-half times the diameter of the plunger.

The speed of the plunger should never exceed 100 feet per minute, from 50 to 60 feet per minute being the best rate, although pumps are frequently run at higher speeds with good results. The slower the speed the greater the efficiency and the less the wear and tear on the pump valves. As pumps will pump warm water only with great difficulty, owing to air troubles, etc., the water, if warm, should enter the pump chamber by gravity, so that the pump will only have to force the water and not lift it.

The indicated horsepower required to work a feed pump may be determined by the use of the formula:

$$I.\ H.\ P. = \frac{W \times 2 \times H}{33{,}000 \times 60 \times .5}$$

Where

$I.\ H.\ P.$ = Indicated horsepower.
W = Weight of feed water in pounds per hour
H = Head of water in feet.

NOTE.—The value of H may be found by multiplying the pressure against which the pump must work by 2.31.

THE WATER GAGE AND TEST COCKS.

Now, we have seen that it is very important that the water level in a boiler should be kept constant, so we must have some means of ascertaining the position of this level at all times, and this we have in the water column, gage glass, test cocks, etc.

Fig. 15 shows the position of the water column and its connections on the boiler. The gage glass is connected between two gage cocks, which should be made of good, tough metal, such as brass, bronze or gunmetal, as inferior metals become brittle with the heat. The passages for the water to and from the water column should be ample, seldom, if ever, as small as ¾ inch diameter. The glass is usually from 10 to 12 inches long, and so placed that when the water is just showing in the glass its level is 3 to 4 inches above the top of the tubes. The normal level is generally at the center of the glass. The bottom gage cock should be furnished with a valve so that it may be opened and steam blown through to clean the system. Both gage cocks should be made so that in case the glass breaks the glass passage can be shut off from the column. In a case like this there must be some way of ascertaining the water level while the glass is out of commission. This is managed by means of try cocks or test cocks. These should be at least three in number, the top one being placed about an inch above the top of the gage glass, one an inch below and the third midway between the other two. On account of the liberal expansion of the glass the glands of its stuffing boxes should be at least 1/16 inch greater in diameter than the glass.

THE STEAM GAGE.

To ascertain the pressure of the steam in the boiler we have the steam gage. This is placed either in direct connection with the boiler (the best way) or on top of the water column. There are two principles employed in the steam gage. One is where the movement of the index finger on the dial is derived from the movement of an elastic corrugated plate, caused by the pressure of the steam against it. The other is where this movement is derived from the movement of a bent, flattened tube of metal which is straightened under internal steam pressure.

The latter principle is the Bourdon, and the one most generally used, as it is both simple and reliable. If a tube thus flattened be closed at one end and bent in the form of the letter U, the application of pressure internally tends to change the shape of the tube to a circular section, which change can only be effected by the partial straightening of the tube, and it is this tendency to unbend that is made use of in the Bourdon pressure gage. One end of the flattened tube is connected to the steam or pressure inlet of the gage and the free end (the

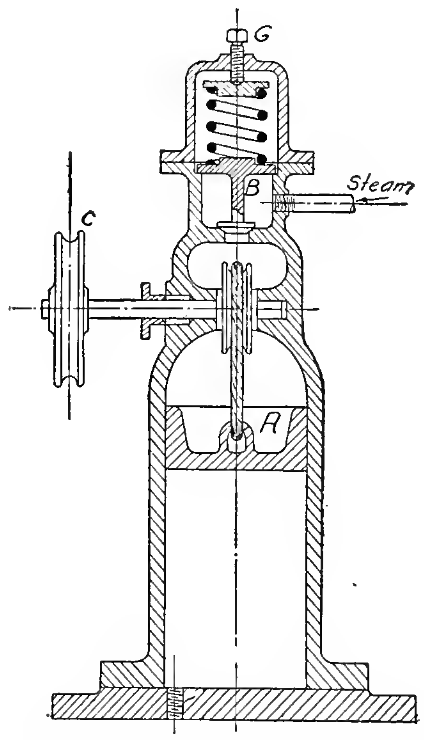


FIG. 16.—SECTIONAL VIEW OF DAMPER REGULATOR.

closed end), which is allowed to move with the internal pressure, is connected to a lever, on the other end of which is a toothed segment. This segment gears into a pinion on the spindle which carries the pointer. To prevent steam from entering the gage and causing injury by heat, the pipe to the gage is usually furnished with a siphon-shaped bend in which the steam condenses, furnishing a cushion of water against which the steam acts but which prevents the steam entering the gage proper.

HIGH AND LOW-WATER ALARMS.

We have seen what precautions are taken against the change in the water level, but sometimes the engineer or fireman may become lax or forget to keep an eye on the gages, water column, etc. To prevent accidents occurring through this negligence there is sometimes furnished what is called a "water alarm," both for high and low water.

One of the principles on which these operate is that a large hollow ball suspended on the water in the water column is connected by levers to a whistle, electric bell or similar alarm, so that when the ball rises or falls to the danger zone

the alarm is sounded to acquaint the negligent fireman of the fact. These alarms are also connected to the steam valve of the feed pump, so that when the ball raises above a certain point the pump is shut off, and when it approaches low water the pump is put into action again.

THE DAMPER REGULATOR.

To automatically regulate the boiler pressure we have the damper regulator, which regulates the heat of the fire. One style of damper regulator is shown in Fig. 16. The valve chamber *B* is connected to the boiler. The spring is adjusted so that it just counteracts the normal pressure on the valve. When this pressure is exceeded the valve lifts, steam is admitted into the cylinder, presses down the piston, thereby rotating the shaft and closing the damper. As the steam pressure falls the damper is brought back to its original position by means of a counterbalance weight on the end of the damper lever.

There are many different types of patent regulators on the market. Nearly all work on much the same principle as has been briefly outlined above, and may be depended upon to do their work effectually.

HOW TO LAY OUT A LOCOMOTIVE BOILER.

The work of laying out a locomotive boiler is becoming more difficult year by year. There was a time when the locomotive was designed, in a measure, to suit the boiler. Today, however, the boiler is designed to gain certain tractive results. The increased power required to draw the heavy trains, both freight and passenger, requires larger boilers and larger fire-boxes. The weight of the boiler filled with water, together with all the fixtures belonging to it, forms a large percentage of the weight of a complete locomotive.

In order to obtain a certain tractive effort, a definite amount of weight is necessary on the drivers, thus the boiler must be shifted backward or forward and often distorted to gain this desired end. For this reason we find boilers varying widely in general construction. Some of the boilers for light and medium weight locomotives, with narrow fire-boxes, are very simple in construction, and comparatively easy to lay out. The heavy locomotive boilers, however, with large Wooten and Belpaire fire-boxes are often very complicated, and therefore difficult to lay out. In treating this subject, the various parts of the boiler will be taken up in their turn, and each one of the pieces forming these parts will be laid out.

DOME.

The dome of the locomotive boiler is usually built in three parts. First, pressed steel dome ring; second, dome sheet; third, pressed steel dome base. The former and the latter are sometimes made of steel castings. The dome base is made in two different ways, one being circular on top, and the other being curved down to the radius of the boiler.

Fig 1 shows a very common construction for a dome with the dome base circular on top. Fig. 2 represents the dome ring. This sheet is flanged in the hydraulic press, and the length L along the neutral line of the sheet after being bent is the same as the radius of the sheet on the flat plate. Allowance must be made for irregularities in the sheared plate.

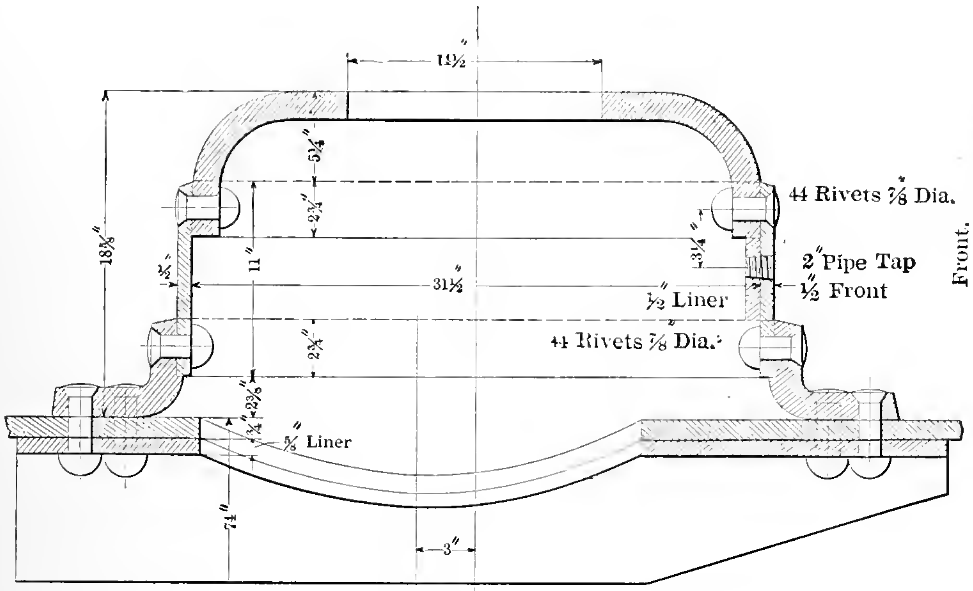


FIG. 1
Dome for Locomotive Boiler.

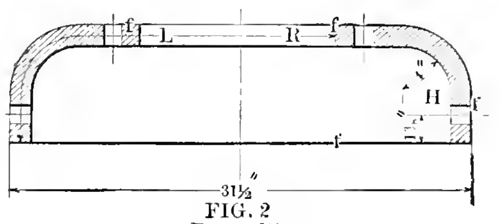


FIG. 2
Dome Ring

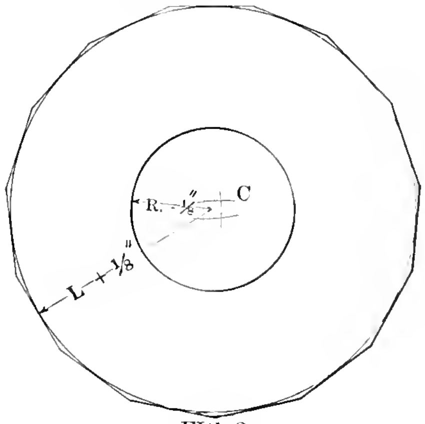


FIG. 3
Dome Ring Before Being Flanged

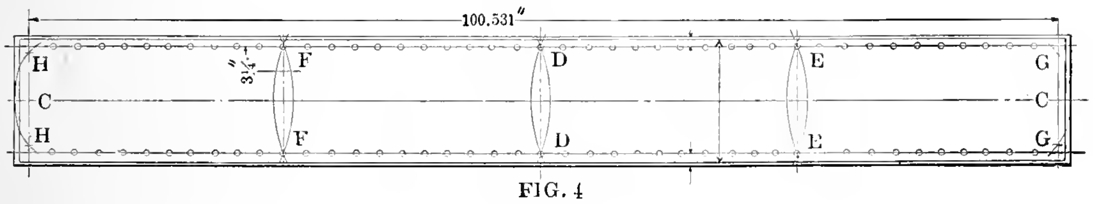


FIG. 4
Dome Sheet

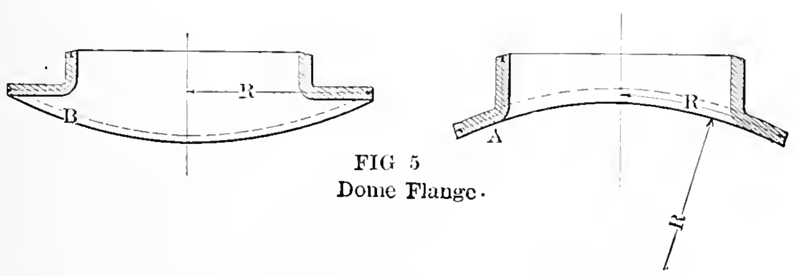


FIG 5
Dome Flange.

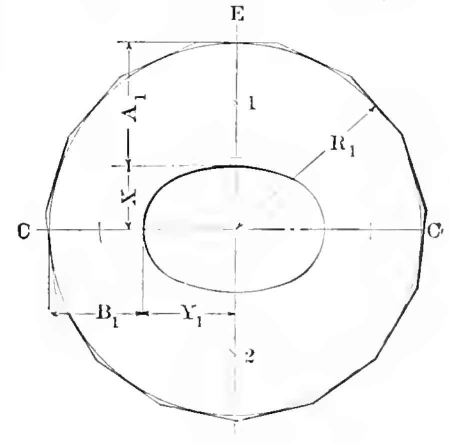


FIG. 6

Fig. 3 represents the flat sheet as it would be ordered from the mills. With a radius of about half the width of the sheet, strike off four arcs at the center of the plate and thus locate the center C. Now strike a circle on the outer edge of the sheet, and if the center is not properly located, shift it one way or the other so as to give the central position. Strike a circle with a radius equal to L, Fig. 2, plus 1/8 inch. Also strike a circle with a radius R minus 1/8 inch. No holes will be put in the sheet before flanging, but the sheet must be turned off inside and outside to the lines which have just been laid out. After the sheet is flanged, as shown in Fig. 2, it is mounted on the boring mill and is turned off at the finish marks, F, to the correct outside diameter; the sheet being flanged a little large so as to give sufficient metal for turning. A cut is now taken off on the bottom, the top and in the bore. The holes for attaching the dome are now laid out to the radius given on the card, the holes beginning either on or between the center line.

The holes are either scribed off from the dome sheet and then drilled, or the dome sheet is shrunk onto the dome ring and the holes drilled in place.

The dome sheet for this dome is welded at the seam. All the holes can be punched in the sheet except those that come near the weld. Fig. 4 shows the sheet as it is ordered from the mills. We first measure this sheet for the proper length and the width. The drawing calls for 31½ inches inside diameter, or 32 inches neutral diameter, as the thickness of sheet is ½ inch. This compares with 100.531 inches, plus a small amount which is necessary for welding. Draw a center line CC the entire length of the sheet. Bisect this line, and at the center draw DD at right angles to CC. Lay off one-half the length of the sheet on each side of the line DD, and draw the lines GG and HH also at right angles to CC. Draw EE and FF midway between the other lines which have just been laid down. This sheet is now quartered. Draw the top and the bottom lines of the sheet parallel to the center line 11 inches apart, and draw the top and bottom rivet lines 1⅜ inches from the edge.

The drawing calls for forty-four rivets in the top and the bottom row. This gives eleven rivets to each quarter. The top and bottom line of rivets are to start on the quarter center lines. Step off eleven equal spaces in each quarter, and center punch for rivet holes. All these holes will be punched except on the vertical seam center line. Lay off a distance from the vertical seam center line so as to give sufficient metal for welding. All the extra metal on this sheet is to be trimmed away and the sheet is to be planed to the lines laid down. The seam will be placed on one of the side centers, let us say the left-side center, and therefore the 2-inch pipe tap will be laid out on the line FF, as all work will be laid out on the outside of the sheet. Four rivet holes for the liner will be laid off to suit the drawing.

The dome base, Fig. 1, is made of 1¼-inch steel. Two views of this dome base are shown in Fig. 5; the dimensions R and R are the same in the two views. Before the plate is flanged, the outer line is circular in form and of a radius R; R, Fig. 6, corresponds to R of Fig. 5. Lay out full size on a spare sheet the two half views of the flange shown in Fig 5. Lay off the neutral line of the sheet and determine the distance A; in a similar way get the length of the neutral line B. Referring to Fig. 6, find the center of the plate by striking several arcs from the outer circumference, then with the radius R, see if this center is correct, as no portion of the circle can extend beyond the sheared edges. Draw a line CC through the center with a straight edge. From the center of the sheet strike off arcs on each side, and from these points as centers strike off two arcs at 1 and 2, and draw the center line EE through these points. Lay off the distance A, equal to A and B, equal to B. We now lay out an ellipse corresponding to X and Y.

The metal inside of this line is to be cut out. This is done by punching a line of holes within ⅛ of an inch of the line of the ellipse. This sheet is turned off on the outside and milled off on the inside to these lines and is then ready to be flanged. After the sheet is flanged the inner surface is planed to fit the exact radius R of the boiler. It is also turned out on the inside to fit the exact outside diameter of the dome ring.

The forty-four rivet holes, Fig. 1, are usually laid off from a templet, or the dome sheet is slipped into place, and the holes are marked off from this sheet. With a back marker the holes are transferred to the outside of the sheet. The holes are then drilled and countersunk under the radial drill. After the sheet has been turned off, Fig. 6, a center-punch mark is put into the sheet along the edge corresponding with the center line CC. These marks are used for locating the sheet in the dies, for flanging and various other operations. They are also used for centering the dome on the boiler. The dome flange is lowered into position, and the holes are center-punched from the inside of the boiler. All these rivet holes are then drilled and counter sunk.

Fig. 7 shows another type of dome that is largely used. It will be noticed that the dome base is dropped down on each side following the radius of the boiler. Two views of this dome flange are shown in Fig. 8. The radius A corresponds to half the diameter of the boiler, 74 inches, or R is equal to 37 inches. The height of the dome flange is 6 inches, and therefore the upper curve of the flange in the right-hand view has a radius of 43 inches. A is equal to 23½ inches radius. This means that the dome base is a circular plate outside before being flanged.

The flat plate is shown in Fig. 9; the radius A corresponds with A in the previous figure. Lay out one-half of the two views shown in Fig. 8. These should be laid out full size on any boiler plate which is convenient. Measure off the length of the neutral lines B and C; these two dimensions should be the same. There may be a slight variation in the radius in the top portion of the dome base in order to bring these two dimensions the same, but usually the top line follows closely to the curvature of the boiler.

Lay off B_1, Fig. 9, equal to B, and strike a circle with a radius D as shown. It will be noticed that the hole in the dome base is circular instead of elliptical, and therefore the sheet can be turned off on the outside and the hole bored out to suit the radius D. Place heavy center-punch marks on the outer

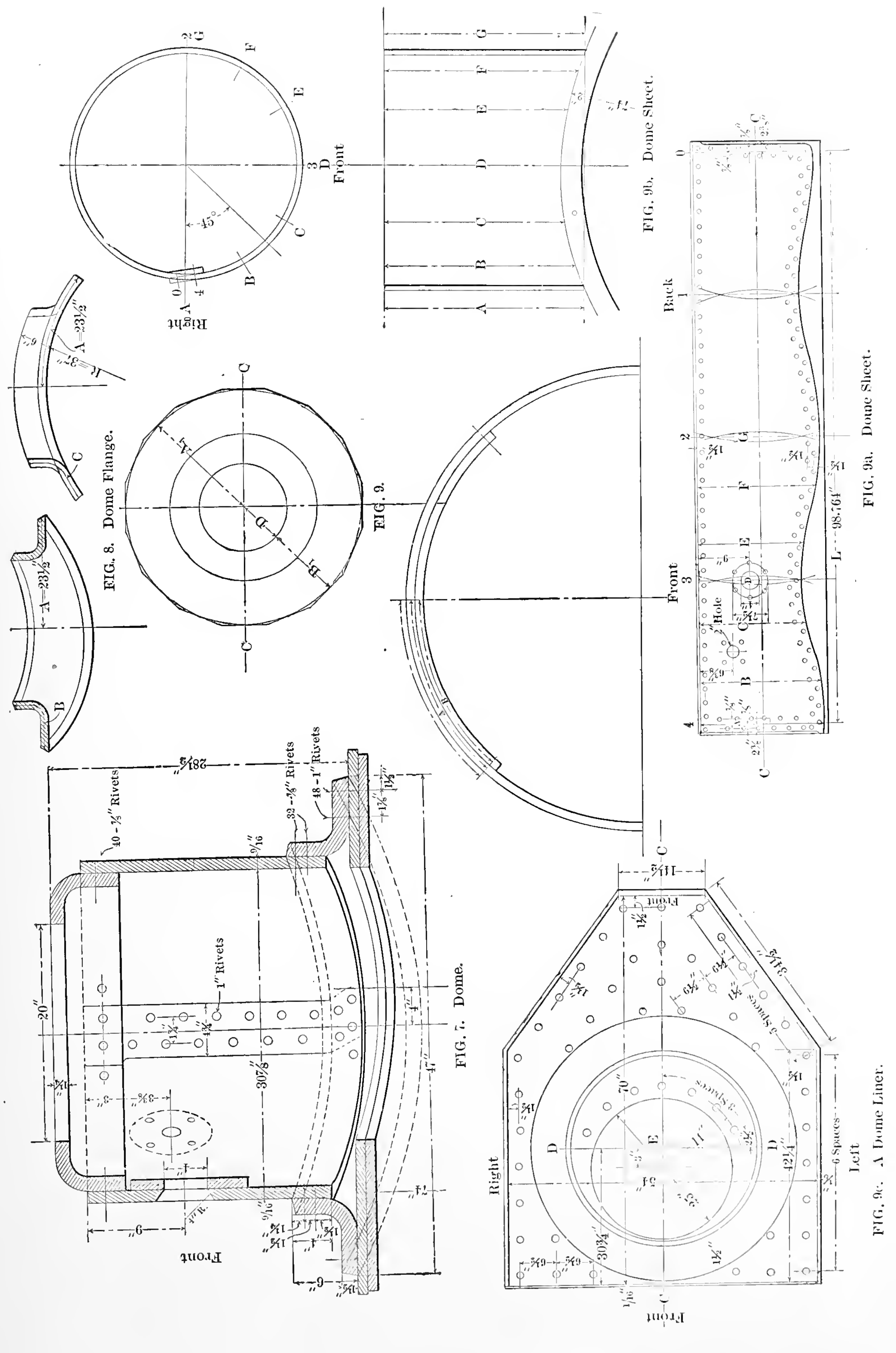


FIG. 7. Dome.

FIG. 8. Dome Flange.

FIG. 9.

FIG. 9a. Dome Sheet.

FIG. 9b. Dome Sheet.

FIG. 9c. A Dome Liner.

edge of the sheet on the line *CC* for centering the dome base for the various operations. The thirty-two rivets shown in the double row, Fig. 7, will be marked off by slipping the dome sheet into place, also the double row of forty-eight rivets will be marked off from the inside of the boiler.

There is a difference in regard to whether the rivets on the outside of the dome base are to be countersunk or not, depending upon the construction of the lagging, casing, etc. This is either shown as a detail on the boiler print or on a special dome card.

The dome sheet shown in Fig. 1 is welded along the seam, while that shown in Fig. 7 is double riveted along the vertical seam. Specifications usually mention which seams are to be caulked inside or outside. The edge of the sheet must be bevelled, and if this can be planed, it should be kept in mind in laying out. This seam is shown on the right-hand side of

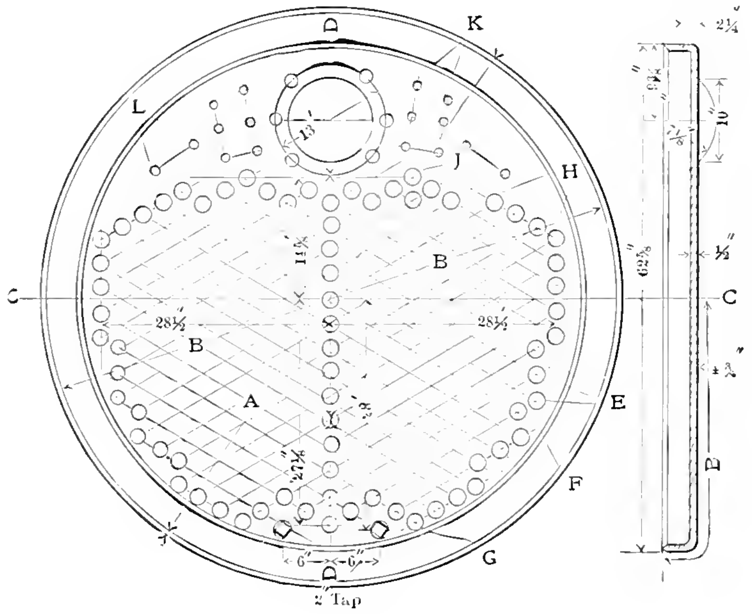


FIG. 11.

the dome. The 9-16-inch plate will probably be ordered from the mills with only sufficient stock allowed for working the sheet up nicely.

Fig. 9a gives the outline of the sheet. The lower edge will be an irregular curve, the vertical lines *A*, *B*, *C*, *D*, etc., being of different lengths. On a spare sheet make a lay-out full size, Fig. 9b, of the dome sheet, the lower edge following the radius of the boiler. We now lay off *A*, *B*, *C*, *D*, etc., in both views and determine the length of the sheet at various points. From the table of circumferences of circles, we find that the neutral circumference of the sheet, which is 31-7-16 inches in diameter, is 98.764 inches.

We also need 2⅜ inches on each side of the seam center line for the seam. We therefore take the total length of this sheet, and the greatest width *A*, Fig. 9b, and measure up the sheet to see if sufficient allowance has been made in ordering. Draw a line along the top portion of the sheet, allowing about ⅛ of an inch for planing. Now draw a line along the left-hand edge at right angles to it, also allowing about ⅛ of an inch for planing. Draw the center line *CC*, which will be half the distance *A* from the top line, measure off 2⅜ inches from the left-hand line and draw the quarter line, number 4. Measure off distance *L* 98.764 inches along the center line, and draw the quarter line *O*; now bisect this distance *L* and draw the quarter line number 2, bisect each half and draw the quarter lines 1 and *B*. Mark the quarter line 3, front, and quarter line 1, back.

Now lay off the lines *A*, *B*, *C*, etc., and step off their corresponding length from the full size lay-out, Fig. 9b. Bend the steel straight edge so as to pass through these points, and draw a nice smooth curved line for the bottom line of the sheet.

Draw the two parallel rivet lines 1¼ inches and 2¾ inches from this line. Draw the top rivet center line 1½ inches from the top line, and the vertical rivet center lines ⅞ inch on each side of the quarter line as shown. Mark off a distance for scarfing on the top right and bottom left-hand corner. This material will be necessary to draw out to form the scarf. Forty rivets are desired on the top row, beginning midway between the quarter lines; this gives ten rivets to each quarter. With the dividers, step off ten equal spaces in each quarter.

The lower line of rivets begin on the quarter line, thirty-two rivets in all, eight rivets in each quarter; with the dividers step off eight equal spaces in each quarter along the lower rivet line. The second row of rivets is spaced midway between these; open up the dividers so as to have exactly half the space and step off this second row of rivets from the first.

Referring to the left-hand end of the sheet, locate the lower and top rivets in vertical seam so that the head will clear the flange and cap, so that you can get at the beam with the caulking tool. The other rivets have five equal spaces. A 4-inch hole is desired on the front center line, together with a liner, which is held in place by six rivets; this hole is laid out 9 inches from the top line. A 2-inch hole is desired on the right-hand side, 6⅜ inches from top line at 45 degrees, also four holes for attaching the flange.

Without any other information this completes the lay-out of the dome sheet. If there are any detail cards of whistle, taps, steam-pipe connections, etc., these should be looked up and laid out before the sheet is finally passed.

DOME LINER.

When the dome, Fig. 1, is used, it is common among some builders to weld the seam on the top center and reinforce the sheet at this point with a dome liner. Fig. 9c shows the dome liner that would be used in connection with the dome, Fig. 1. This ⅝-inch sheet would be ordered from the mill as a shaped sheet, and with a liberal allowance for trimming. Measure up the sheet for width and length, be sure that everything is correct. Draw the center line *CC*, and draw the front line of the dome liner, allowing about 1-16 inch of metal for truing up. Draw the left-hand line of the sheet, allowing about ⅛ inch for planing.

The boiler print gives location of rivet holes, and in order to match up with the corresponding holes which would be put into the dome course, a full size view of the first course and dome liner is laid out on a spare sheet. We will settle on laying out the holes to scale along the neutral line of the

dome liner *B*, Fig. 10. When these same holes are laid off on the first course, the holes correspond with the dome liner, as laid off along the neutral line *B*, the radial lines are drawn to *A*. The run of the line *A* is obtained with the wheel, as there will be considerable difference between the lines *A* and *B*, the further the holes are from the top center.

Lay off the dome center line *DD*, Fig. 9c, 30¾ inches back from the front line; 3 inches from this line we strike a 25-inch circle for the throttle-pipe hole. We now strike a 14-inch radius from this hole, and lay off six equal spaces for rivets as shown. From the dome center *E*, we strike the outer and inner line of the dome flange, as all the rivets must be kept out of this line. Draw a rivet line around the sheet 1½ inches from the edges. Lay off six equal spaces in the right and left-hand side, and five equal spaces along the tapered portions. The remaining rivet holes are laid off from these lines to the figures given.

In welding the top seam of the dome course, a number of the rivet holes near the seam are omitted. These are laid off and drilled after the seam is welded. After all the holes are put into the first course, the liner is brought from the bending rolls, and put into position in the dome course, and all these holes are punched off from the outside of the dome course.

FRONT TUBE SHEET.

The front tube sheet will come from the mill, ordered with about ¼ inch for truing all around. Fig. 11 represents two views of this sheet. We measure off the length *B* along the neutral line of the sheet and strike the radius *B*, corresponding to it from the center of the circular half-inch sheet. Draw a center line *CC*, and at right angles to it draw the center line *AA*; 28½ inches on each side of *AA*, draw the tube center line. Divide the distance between these center lines into twenty-one equal spaces, and 14⅝ inches above and 27⅛ inches below the center line *CC* draw the limiting tube center line.

Divide the distance between these two lines into fourteen equal spaces, draw tube circles at each one of these points. Now lay out the five tubes at the extreme right and left side; these are spaced midway between the center tubes. In a similar manner, we lay out the three tubes marked *E*, and then the four tubes marked *F*, and five tubes marked *G*, and finally, the three remaining tubes and 2-inch pipe tap for wash-out plug. These tubes will be laid out on each side of the center line. In a similar manner we lay out the four tubes marked *H*, the three tubes marked *J*, and the four remaining tubes, all of these being marked out on each side of the center line. We now have all the limiting tubes outlined. Draw the diagonal lines as shown; the intersection of each one of these lines gives the location for another tube.

In order to be sure that the construction is correct, draw vertical and horizontal lines corresponding with tube centers; if the construction is accurate, all of these lines will cross at a point. This is a good check on the work.

The steampipe hole is shown 10 inches in diameter; this will be laid out to suit work, and also six rivets in a circle 13 inches in diameter. We now lay off six rivet holes on each side of the center from the tee-iron connection, and also the two holes marked *L* for the stay-rod connection, the figures for these rivet holes being given on the boiler card. In some shops the majority of these holes are punched before the sheet is flanged. Those holes coming too near the flange are omitted and are punched after the sheet is flanged.

All the center-punch marks for tubes and rivets along the outer edge must be checked after flanging, and these centers which are drawn must be correct. Center-punch marks are put into the sheet locating the center line *CC* and *BB*. Lay off twenty-five equal spaces in each quarter, beginning holes on center line and 2¼ inches from back of sheet. Also lay off line along the sheet 4¾ inches from the back edge. This sheet is now turned off to this line and the steampipe hole is machined to size. Also tube holes are either drilled or reamed, as the case may be, according to practice or specifications.

CHAPTER II.

The various parts of the dome, front sheet, etc., have been laid out, and we will now take up the laying out of the first course of the locomotive boiler. The method of attaching the first course to the smoke-box sheet varies, depending upon the size of the boiler, and also with the methods of attaching the various parts, and in many cases is made to suit the taste of the master mechanic.

A common construction is shown in Fig. 12, where the first course continues on through and is riveted direct to the smoke-box sheet. The tube sheet is set back with an even spacing of the rivets and is riveted directly to the first course.

Another construction which is frequently seen is to have a ring about 1 inch thick, and in length about 12 to 15 inches. The front tube sheet is riveted to this ring while the first course enters inside the ring and is riveted to it, the smoke-box sheet being riveted to the front end. Still another construction which is frequent on medium and small-sized boilers is to have the first course extend on through far enough to receive a solid steel ring from 3 to 4 inches wide, and from 1½ to 3 inches thick, the smoke-box sheet being riveted outside of this ring.

The locomotive boiler shown in Fig. 12 is a 64-inch boiler, which has recently been put in operation on one of the Western roads. It shows the boiler "fore shortened." The first course is shown 64 inches outside diameter, by 106 11-16 inches long. Also this sheet is to be 11-16 inch thick. The neutral diameter of the sheet, therefore, is 63 5-16 inches. From the table of circumferences we find the figures corresponding with 63 5-16 inches, as follows:

Circum. corresponding to		63¼ inches diameter is	198.706
"	"	1-16 inch diameter is	.196
"	"	63 5-16 inches diameter is	198.902

This will be the length of the sheet when it is laid out on a flat surface. The sheet as it will come to the laying-out bench will have an allowance for trueing all around the edges. We now measure up this sheet for length and width. If everything is found correct, we draw a line along the top about ⅛ inch from the edge for planing. On each end of the sheet measure off a distance 106 11-16 inches and draw the back line

of the sheet. Now bisect the distance between these two lines and draw the center line *CC* of the sheet. With the trams and a liberal radius *A* square off the end line of the sheet, allowing about ⅛ inch for planing. Now measure off on the center line a distance of 198.706 inches. The drawing calls for this seam on the right side 20 inches up from the center. Measure off this distance from the left-hand edge of the sheet and draw the right quarter center line. Measure off a distance of one-quarter of the length of the sheet, or 49.677 inches from the right quarter line and draw the bottom quarter line at right angles to *C-C*. Also lay off this distance from the bottom quarter line and draw the left quarter line. If the construction has been accurately made the distance from the top quarter line to the right-hand edge of the sheet should be 29.677 inches. This distance, together with the 20 inches at the left-hand edge of the sheet, should equal one-quarter the length of the sheet. Check these distances over to see that everything is correct. Mark the quarter lines as shown, and mark the front end of the sheet "Front."

Draw a rivet-center line 1¼ inches from the top line. Draw another rivet-center line 4 inches from the top line. These rivet-center lines are for the front tube sheet and smoke-box sheet connections. The drawing calls for 100 ⅞-inch rivets, which will give twenty-five for each quarter. As nothing is specified to the contrary, both rows of rivets will begin on quarter center lines. Divide the distance between both quarter lines and right quarter line into twenty-five equal spaces. Lay off twenty-five equal spaces in each one of the other two quarters. Lay off nine equal spaces from the right-hand line to the left-hand edge, and lay off sixteen equal spaces between the top quarter line and the right-hand edge of the sheet. The rivets in the first and second row will come opposite each other all around the sheet.

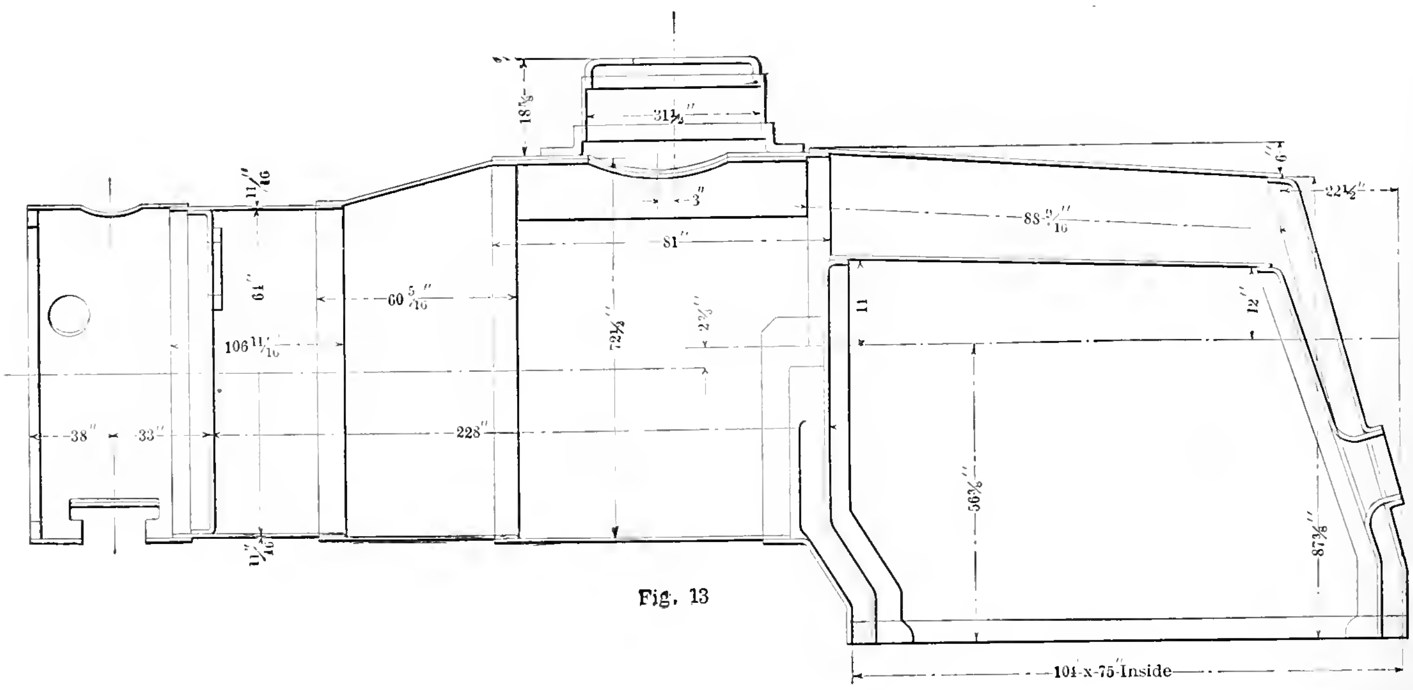


Fig. 13

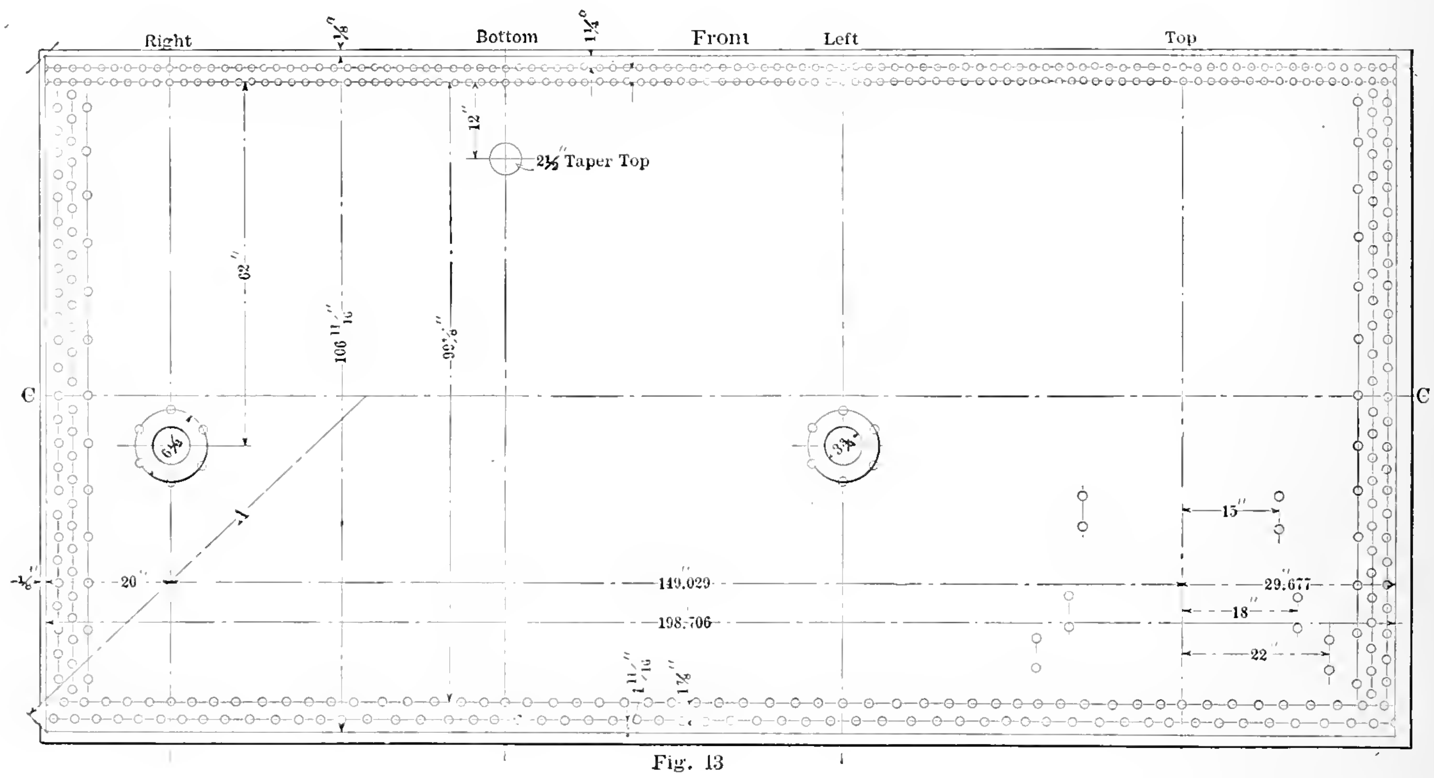


Fig. 13

Lay off a center-rivet line 1 11-16 inches from the bottom

line, also another rivet-center line 39-16 inches from the bottom line. The center lines are for the rivets on the rear end of the sheet. The drawing calls for fifty-six 1⅛-inch rivets. This will give fourteen equal rivets in each quarter. Begin the front line of rivets on the quarter-center line, and lay off five and one-half equal spaces from the right quarter line to the left-hand edge of the sheet. Now lay off eight and one-half equal spaces from the top quarter line to the right-hand edge of the sheet. In the front row of rivets strike off, with the dividers, the rivets in the back line, half a space from those in the front line.

Draw three rivet-center lines on each end of the sheets to correspond with figures for the triple riveted seam. Divide the distance between the front and the back inner row of rivets into twenty-six equal spaces, and run a line of center punch marks along the front row of rivets to correspond with the points

GUSSET SHEET.

The gusset, or slope sheet, is a very common sheet on a locomotive boiler, as there are very few large boilers that do not have a gusset sheet. Fig. 12 shows one of these sheets uniting the dome course with the first course. This sheet, when rolled out flat, is curved on the edges, and in order to get the sheet to match up properly the surface must be developed.

A larger view of the gusset sheet is shown in Fig. 14. After this sheet comes from the rolls the front portion must be flared out and the back portion drawn in, in order to bring the surfaces correct for riveting. The bending line is made about 1 inch from the line of the sheet, front and back, or 6¼ inches from the front, and 6½ inches from the backs will be the line of the sheet. L will be the length between the bending lines. The total length of the sheet will be 60 5-16 inches.

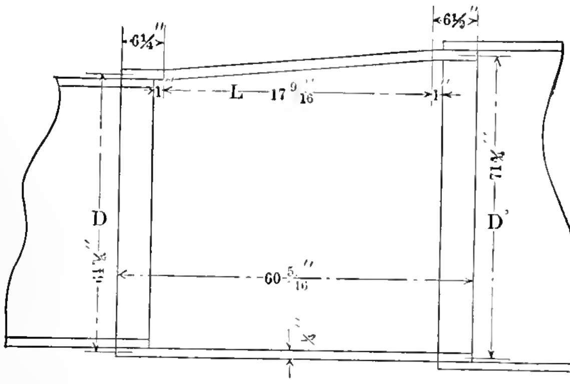


Fig. 14

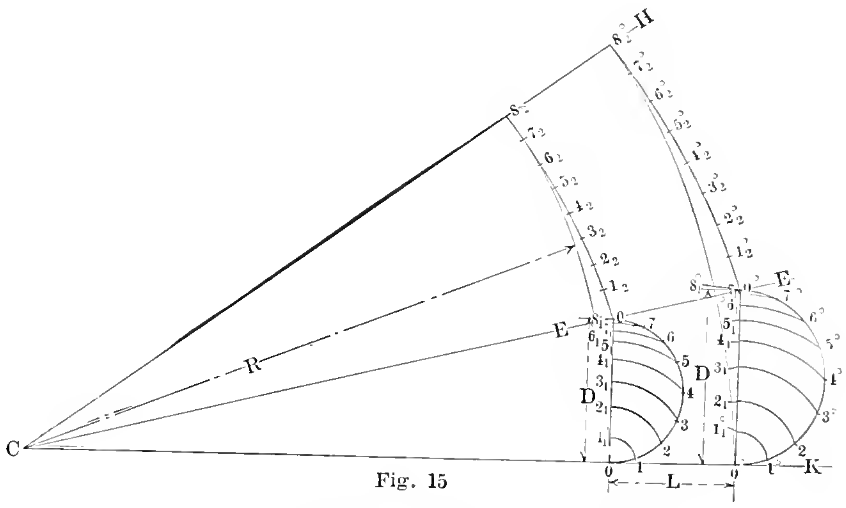


Fig. 15

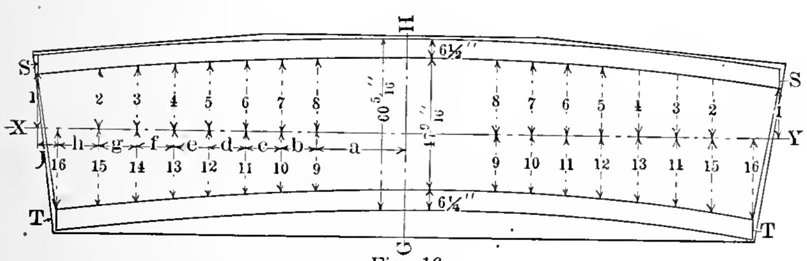


Fig. 16

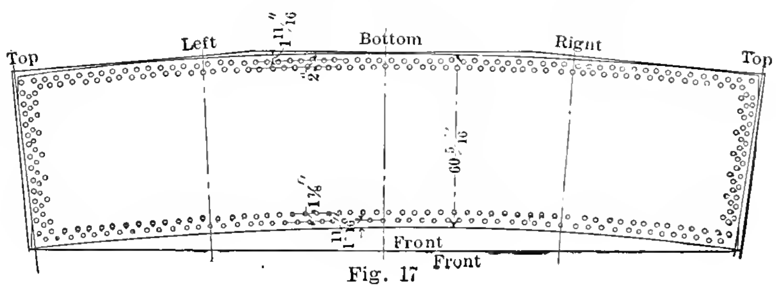


Fig. 17

laid out. With the dividers step off the rivets in the second line half a space from these. Now lay off the rivets in the third line, omitting every other space as shown. The rivets in the right and left-hand side of the sheet are laid out exactly the same. The drawing calls for injector check openings, right and left, on the side-center lines, 62 inches back from the center line. Strike a 3¾-inch circle for the hole, also strike a 6½-inch circle and lay off six rivets 12 inches back from the tube sheet rivet center line. Lay off a 2½-inch taper tap hole on bottom center.

This sheet will require six stay-foot connections; from the detail of the front tube sheet we get the distance these stays come from the top center lines, 15, 18 and 22 inches respectively. We lay off these six pairs of rivet holes to suit, to the right and the left of top center line. In the absence of any further information this completes the laying out of this sheet. Several sand-box studs will be required; these will be marked off from the casting and drilled to suit.

Let D be the front neutral diameter of the sheet and D the back neutral diameter of the sheet. In order to get the shape of this sheet when it is laid out on a flat surface, we proceed as follows: Select a nice clean sheet and draw a base line CK, Fig. 15. This line must be continued so as to obtain the center C from which the reference circles are struck. The length R depends upon the shape and the diameter of the boiler, and is found as follows:

Let D = front neutral diameter,

D° = back neutral diameter,

L = distance between bending line of sheet. Note that this distance is not the total length of the sheet.

$$D^\circ : R :: (D^\circ - D) : L,$$

$$R \times (D^\circ - D) = L \times D^\circ$$

$$R = L \times \frac{D^\circ}{D^\circ - D}$$

We now substitute the values D° and L and obtain

$$R = 47\ 9\text{-}16 \times \frac{71\frac{3}{4}}{71\frac{3}{4} - 64\frac{3}{4}}$$

$$R = \frac{47.563 \times 71.75}{7}$$

$$= 487.52 \text{ inches.}$$

We could not, consequently, lay this out full size, nor will it be necessary to do so. This construction will be made to a scale of 1½ or 3 inches = 1 foot, depending upon the size sheet that we may have at hand. Referring to Fig. 15, draw the line D and D° at right angles to CK, making $D = 64\frac{3}{4}$ inches and $D^\circ = 71\frac{3}{4}$ inches, and making $L = 47\ 9\text{-}16$ inches. Lay off the radius $R = 487.52$ inches, and thus determine the center C. All the elements of this cone-shaped surface will point to the center C. Continue the top slope line EE with a the point 8° with the second dividers strike off the arc $1^\circ{}_2$; with a pair of dividers measure off the distance from the small reference circle to the point 7_1. From the reference circle strike off an arc locating a point 1_2. In a similar way strike off an arc from the large reference circle and determine the point $1^\circ{}_2$. These are two points of the developed surface. From 1_2 strike another arc with the first pair of dividers, from $1^\circ{}_2$ strike an arc with the second pair of dividers. Now transfer the distance from the reference circle to point 6_1, and thus determine the location of the points 2_2 and $2^\circ{}_2$. These are two more points of the developed surface. Continue this operation until the points 8_2 and $8^\circ{}_2$ are arrived at. If the construction is properly made, the line 8_2 and $8^\circ{}_2$ if continued will pass through the center C. This is a check on the construction, and if it does not come out right the work will have to be gone over again.

Bend the steel straight edge, so as to take in these points,

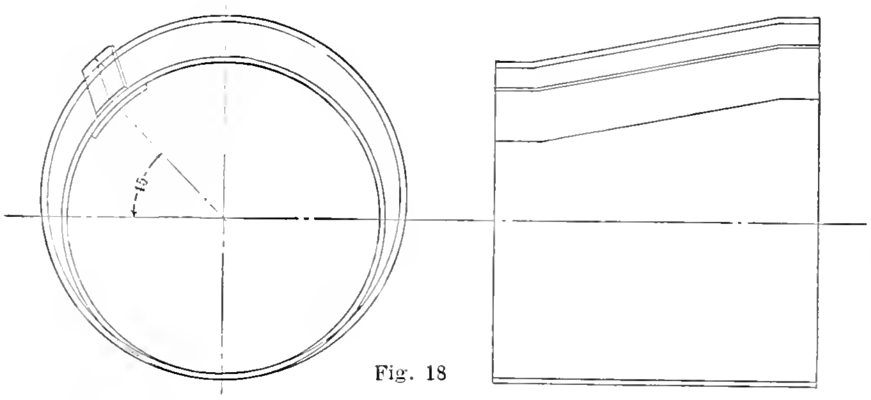


Fig. 18

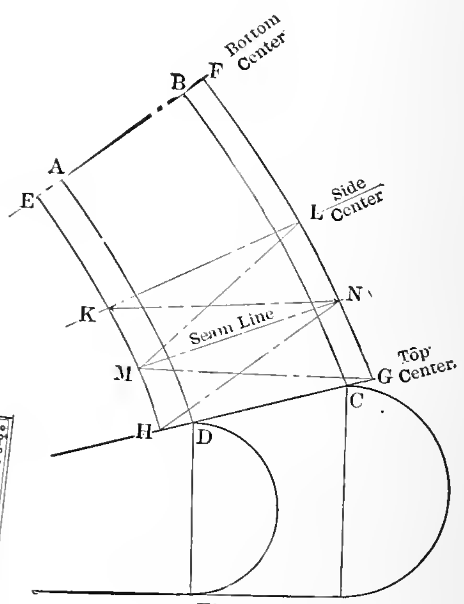


Fig. 19

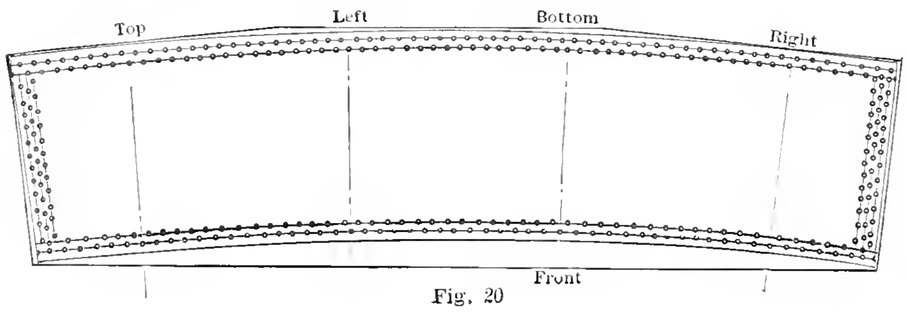


Fig. 20

straight edge. This should pass through C. We now check up this construction to see that everything is correct.

Strike a semi-circle on D and D°, and divide each one of these half circles into any number, say eight, equal parts. Number the points from zero to eight on the small circle and from 0° to 8° on the large circle. Put the point of a pair of trams on the point zero, and strike an arc from 1 to 1. Similarly strike an arc to points 1, 2, 3, 4, etc., and in the same way project the points in the large circle on to the diameter D°. Number these points 1_1, 2_1, 3_1, etc., and $1^\circ{}_1$, $2^\circ{}_1$, $3^\circ{}_1$, etc.

From zero, with the trams on the center C, strike the small reference circle, open up the trams and strike the large reference circle from the same center. Look up from a table of circumferences the half circumference of D, and lay this out along the straight line. With the dividers, step this off into eight equal parts. In a similar manner lay down along another straight line the length of the large half circle. Step this off into eight equal parts with another pair of dividers. From point 8, with the dividers, strike off an arc 1_2, and from and draw the two smooth curved lines. This represents one-half of the tube sheet, EC being the top center line and AH being the bottom center line. We will now hunt up the sheet which was ordered for this gusset plate, and measure off the over-all length and width of the development, to see if it is large enough. To make this clear we will refer to Fig. 16.

The two curved lines which have been laid out in the previous figure are the bending lines of the sheet. To this must be added 6¼ inches on the front and 6½ inches on the back, for the seam. The drawing calls for butt seam on the top center. Therefore, this sheet will be symmetrical about the line CH. On a previous layout, draw the reference line XY at right angles to CH. Draw perpendicular lines about 8 inches apart for ordinates. Number these ordinates 1, 2, 3, etc. Stretch a chalk line XY on the gusset sheet and shift it back and forth until the best position is found. Then draw the line XY the full length of the sheet. Lay off the ordinates from the original layout to correspond with the other dimensions, 1, 2, 3, etc. Bend the straight edge and draw a line

through these points. Step off the width of the seam from the bending line and draw the outer edge of the sheet.

The portion at *S* and *T* will be drawn parallel to *CH*. We now proceed to lay out the rivet holes. Draw a curved line for rivet centers 1 11-16 inches from the top edge. Draw another curved line 2 inches from this line. The drawing calls for sixty-four rivets 1¼ inches diameter. This gives sixteen rivets in each quarter. We now divide the sheet into four equal parts. Along the top and bottom lines draw the right and the left quarter line through these points and also the bottom center lines. Draw the two curved lines for rivet centers along the bottom of the sheet 1 11-16 inches from the edge and 1⅞ inches from this line. The drawing calls for fifty-six rivets, or fourteen in each quarter. Begin the front row of rivets on center lines and step off fourteen equal spaces in each quarter.

We now have the rivets to lay off on each end of the sheet to correspond with the butt triple-riveted seam. We lay off the rivets on each end to correspond with the blue print for this seam. Four more lines should be marked off on this sheet midway between the quarter lines, which should be used for lining up the sheet in the rolls.

When the seam does not come on the top center, the work of laying out the sheet is somewhat different than that shown in Fig. 17. We will take the case where a seam is desired on the right-hand side of the boiler at 45°, as shown in Fig. 18. We make the layout for the development for this sheet as shown in Fig. 19. The development is made the same as that shown in Fig. 15. *A, B, C, D* represents the development of the sheet up to the bending line, and *E, F, G, H* represents the sheet, including the seams; *GH* is the top center line, and *EF* is the bottom line; midway between these two we draw the side center line *KL*. Midway between the top center line and the side center line, we draw the seam line *MN*. Having this construction completed, we can proceed to lay out the gusset sheet with the seam on the side 45° up from the center line.

On a spare sheet, with a scale of 1½ inches to the foot, lay out this sheet as follows: Draw a bottom line, Fig. 20; from Fig. 19 measure off *FL* and *EK*, and transfer these dimensions to Fig. 20, laying out the points on each side of the bottom center line. We now have the sheet laid out up to the right and left quarter lines. Transfer the portion *K, L, N, M* to the right-hand side of the right quarter line. Transfer the portion *K, L, G, H* to the left-hand side of the left quarter line, making the line *KL* coincide with the left quarter line. The extreme portion of this figure will give the top center line of this sheet. Now transfer the portion *M, N, G, H* to the left of the top center line, making *HG* correspond with the top center line. We thus have the complete layout of the gusset sheet.

Draw a reference line the entire length of the development, and lay off ordinates the same as in Fig. 16. This gives the general outline of the sheet, and from this we can lay out the work of the sheet which has been ordered for the purpose. Fig. 20 shows the sheet as laid out. Mark off eight equal spaces to the left of the top line and punch the holes to correspond. Lay off the top rivets half a pitch from these. Repeat this operation on the right-hand top portion of the sheet. Lay out seven equal spaces on the lower left-hand portion and locate the rivets in the next line half a pitch from these. Repeat this operation in the lower right-hand portion. The rivets for the butt seam are laid out to suit the detail drawings of the seam in the same way as in the previous case.

The most difficult seams to keep tight about a locomotive boiler are those around the fire-box. No matter how good a job is made of these seams, we are sure to have more or less trouble with them after the boiler has been in service for some time. For this reason special pains should be taken with these seams in order to make an extra good job. We will take up the fire-box sheets in their order as follows: The fire-box back sheet, the fire-box front or tube sheet, fire-box continuous crown or side sheet, fire-box side sheet and fire-box crown sheet.

THE FIRE-BOX BACK SHEET.

Fig. 21 shows a fire-box back sheet. The rear end of the boiler is sloped off to the front as shown. The center line of the boiler is 18½ inches down from the top of the crown sheet. In order to get the length of the sheet before flanging, measure off the length of the neutral line *L*. For width, lay off in a similar manner the length of the neutral line around the sheet at the line of the greatest width as shown at *A*. This portion must be wide enough to go around the first through rivet of the water space frame.

Fig. 22 gives the shape of sheet. Draw the center line *CC*, also the boiler center line *EE*. From the center line measure a distance 30¼ inches and draw the line *DD*. We must now lay off the fire-door holes *A* and *B*. These holes are oval, 16 inches by 20 inches inside. Lay this fire-door out full size and get the length of the neutral line *A*, Fig. 21, of the sheet after the door has been flanged. From the distance *B*, and also from the other section of the door, we can obtain the distance *C*. These two figures are the length and the width of the oval sheet before flanging.

Lay out these ovals, Fig. 22, as shown. These holes will be punched out and the outer edge milled off smooth before being flanged. Draw the limiting line of the sheet, which will have sufficient metal for seams, plus an allowance of from ¼ to ½ inch for trimming after the sheet has been flanged. If the back fire-box sheet is not bent too sharp, the holes can be laid out and punched before the sheet is flanged. But where the metal draws considerably in flanging, these holes will have to be laid out and punched after the sheet comes from the press.

The layout of this sheet is given in Fig. 23. Draw the center line of the sheet *CC* and draw out *DD*, the center line of the fire-doors. On the center line lay off a distance corresponding with the bottom line of stay-bolts. Draw the line *EE*, laying off nine equal spaces on each side of the center 4 inches apart. On the center line *CC*, lay off two 4 inch spaces and draw the center line *FF* and *GG*. Lay off nine equal spaces on the third line 36¾ inches on each side of the center, draw lines to locate rivets *FF* as shown. From the figures on the boiler card lay off the rivets around the fire-doors. Lay out the holes in the intermediate points; draw center lines *HH* and lay out holes to suit. Continue laying out one row of rivets, one after another, until the top of the sheet is reached; check

up the length vertically to see that you are not gaining or losing in the overall distance, also draw two lines along the bottom of the sheet and lay off twelve equal spaces on each side of the center line to correspond with the first through rivets on the mud ring corner. Lay out rivets in top row and space from these as shown. After the sheet is flanged, the holes for the rivets for the side and crown sheets will be laid out.

FIRE-BOX TUBE SHEET.

The fire-box tube sheet in many boilers is a plain sheet, the outer edge being flanged to make the connections to the side and crown sheets. In other boilers, however, the fire-box tube sheet is quite complicated for laying out and flanging. Fig. 24 represents a sheet which is commonly seen on heavy locomotive boilers. The sheet has a set of 7⅛ inches and the flange on the bottom is 6 inches deep. Lay out the cross section of the sheet on the ½-inch plate, which has been ordered for this sheet.

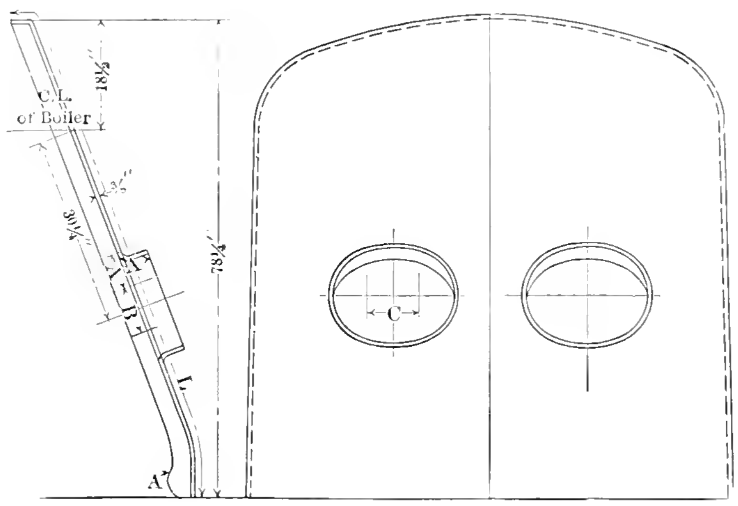


FIG. 21.

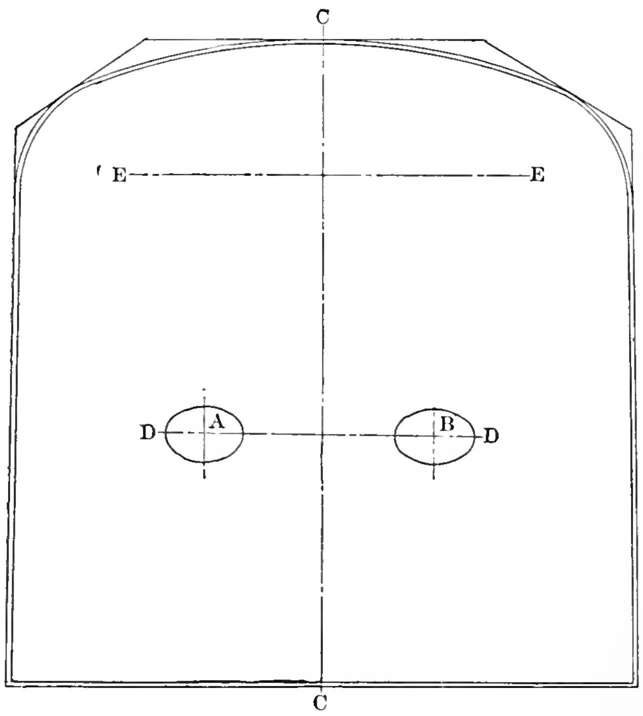


FIG. 22.

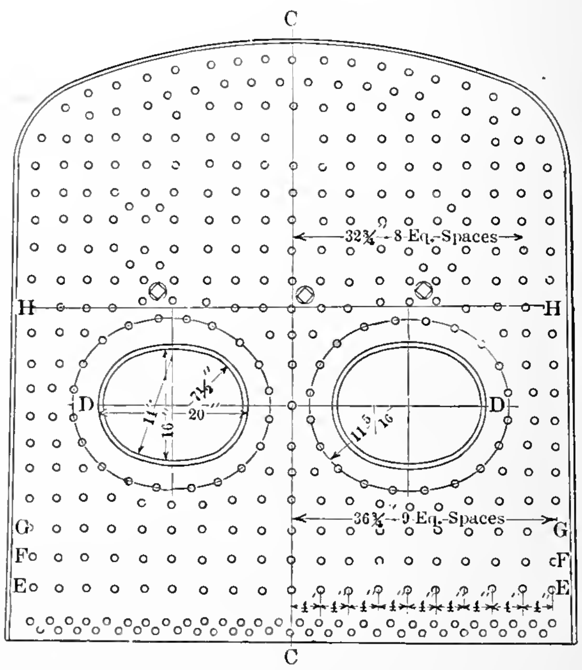


FIG. 23.

Measure off the length L of the neutral line of the sheet. To this length must be added the taper portion at A in order to get the full length of the sheet necessary. These lower taper lines at A and A will become nearly straight when the sheet is flanged. The amount to allow depends upon the set of the sheet; the greater the set and the deeper the flange, the greater the allowance will have to be. To get the full length of the sheet through the deepest portion of the flange, measure off the neutral line M at this point. This is the greatest width of the sheet.

Now lay out the outer line of the flanged sheet from the boiler card and lay off the width of the flange outside of this. We now obtain the outer line B and B of the sheet. Draw the center line CC on the plate which has been ordered for this sheet, allowing at least ¼ of an inch for trimming at the top of the sheet. All the extra metal is to be removed and the outline of the sheet must be smooth before it can go to be flanged.

Fig. 25 shows this sheet as it will appear laid out on a flat sheet. All the holes will be laid out and center punched before the sheet is flanged. Draw the main center line CC of the sheet; at right angles to CC draw the boiler center line DD. All the boiler tubes are to be located from these two lines. The highest tubes are 11⅛ inches above the center, and the lowest tubes 30⅝ inches below the center. Divide this distance into fourteen equal spaces. The extreme tubes are 28½ inches on each side of the center; divide this distance into eleven equal spaces, draw the tubes on the center lines as shown, then begin on top and lay out the limiting tubes one after the other, keeping the boiler card in front of you as you go along. The five extreme tubes on each side fall midway between the tubes on the center line. Follow on down along the curve of the boiler and lay out all the limiting tubes in the lower portion; repeat this same operation on the other side.

Draw diagonal lines through these limiting tubes as shown in Fig. 25. These lines should cross the tube centers on CC, also these intersections should form straight lines vertically and horizontally. Before laying out any of the remaining

tubes, see that all these lines check up properly; if they do not true up, they must be shifted and corrected. The remainder of the tubes can now be laid out with reasonable assurance that everything is all right. Draw two parallel lines along the lower edge of the sheet for the water-space rivets.

Lay out eleven equal spaces along lower line, spaced on each side of the center to the first through rivets. Step off the next row half a space from these; draw four parallel lines at right-angles to *CC* to the figures given. Start on the right-hand side and lay out all the rivets on the lower line. Sum up the dimensions and check the overall to be sure that you have neither gained nor lost in laying out these given units.

Lay off the rivets to the figures, one row after another; draw a circle with 34¾ inches radius and step off the desired number of spaces. Also draw a circle with 40 inches radius. Lay off the remainder of the stay-bolt holes for these rivets. Complete on each side of the sheet; first measure off the extreme rivets to see that every thing checks up with the figure on the boiler card. With a pair of trams transfer this construction to the other side of the sheet. The holes *AA* fall on the curved portion of the sheet along the corner and would be laid off after the sheet is flanged, also the holes for the rivets for the side and crown sheet would be laid off after the sheet is flanged.

FIRE-BOX SIDE AND CROWN SHEET.

The fire-box is subject to such high temperature that the sheets gradually burn away, and the thicker the sheet the quicker it will burn away. The seams have a double thickness at this place. For this reason these seams are difficult to keep in order. The fire-box top and side sheets are made in three pieces; this gives two longitudinal seams, one on each side of the boiler. In order to overcome the disadvantage of these two seams, the side and crown sheets are made in one continuous piece as shown in Fig. 26. This sheet is laid out in the following manner: Referring to the right-hand view, we lay out the neutral line of the front and back of the sheet. Lay off points 1, 3, 5, 7 and 8 on the front neutral line, and points 0, 2, 4, 6, 8 on the back neutral line. Also lay out these points on the left-hand view and number them 1, 3, 5, etc., and 0, 2, 4, etc., connect these points by diagonal lines as shown.

Lay out a right-angle *A*, *B*, *C*, and lay off the length of the element 0-1 along *BC* as shown at *X*. Measure off the distance 0-1 on the right-hand view and lay this off along *BA* as shown at *Y*. Measure the length of the diagonal *Z*. This is the true length of the element 0-1. In a similar manner obtain the true length of the elements 1-2, 2-3, etc.

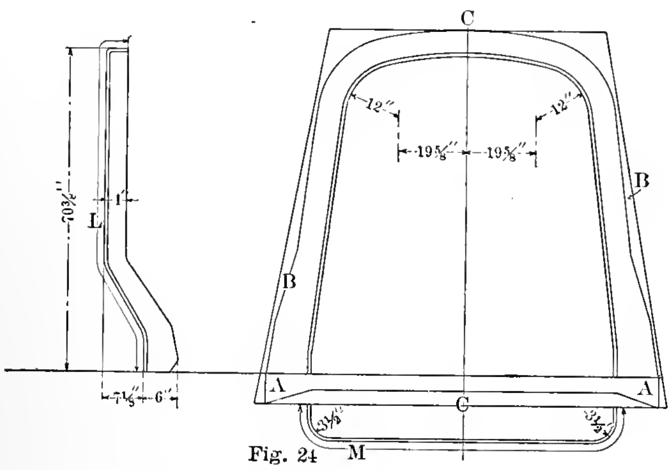


Fig. 24

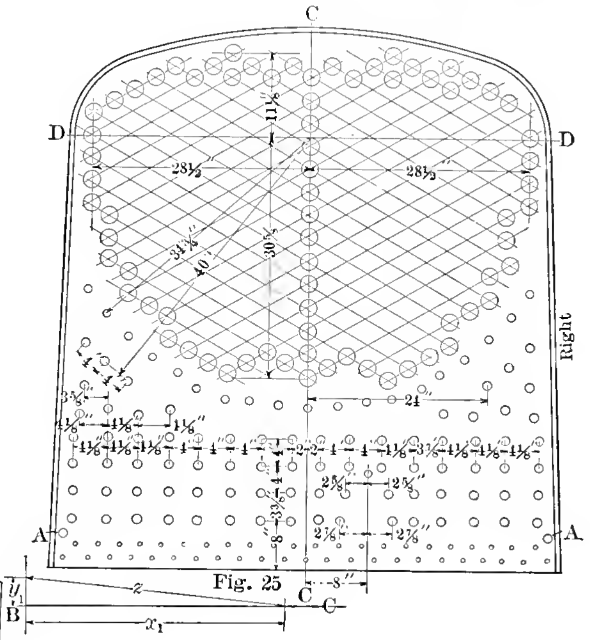


Fig. 25

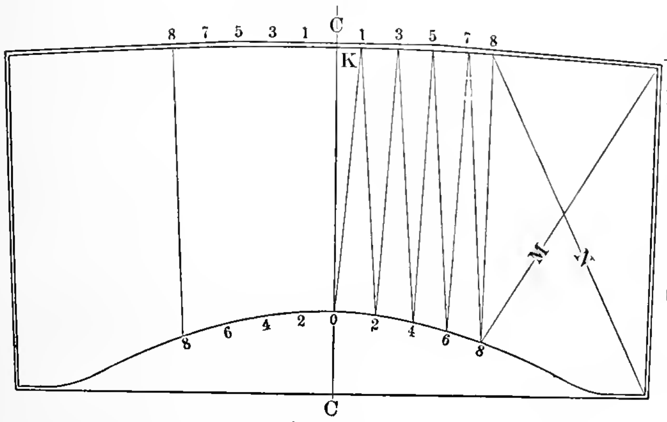


Fig. 27

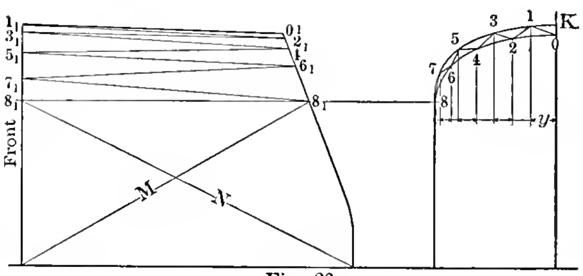


Fig. 26

Having determined the true length of these elements we can proceed to lay out this sheet. Draw a center line *CC* on a good large sheet, Fig. 27. From *O*, with the true length of the first element *B*-1 as a radius, strike off an arc as shown. Measure off the length of the neutral line *K*-1, Fig. 26, and strike off an arc from the center line *CC*, Fig. 27, cutting the first arc at 1, draw the line O-1. From zero with a radius equal to the length of the neutral line from 0 to 2, strike off an arc, and from 1 as a center with a radius equal to the true length of the second element, strike off an arc. This locates the point 2. In a similar manner we strike the length of the neutral line 1-3 and the true length of the element 2-3. Continue this layout until we get to the element 8-8 on the right-hand side. From this element on down to the bottom of the

sheet, the plate is straight, and therefore we transfer this portion to Fig. 27. The length of the diagonals M and N are the same as found in Fig. 26. Having laid out this much of the sheet we can determine the overall length and overall width of the sheet.

If this sheet has been ordered from the mill it will probably have plenty allowance for trimming all around. If the sheet has not been ordered, we take a stock plate as near the size as possible and make the layout exactly as shown in Fig. 27. All the holes for the stay-bolts and rivets will be laid out on this flat sheet in a similar manner given for the layout of the side and crown sheet, which will be given directly

FIRE-BOX SIDE SHEET.

Fig. 28 represents a fire-box side sheet with a longitudinal seam for the crown sheet connection. On a much larger plate than the one that has been ordered for this sheet, we make a large layout of the fire-box, showing mud ring and front and back tube sheet. This will be used after the front and rear sheets have been flanged to lay out the rivet holes in these flanged holes. Having made this layout as shown in Fig. 28, that portion which pertains to the side sheet itself can be transferred to the actual sheet, Fig. 29, upon which this layout is to be made. Draw a line along the top of the sheet, allowing about ⅛ inch for planing, measure up the length and width from the large layout and find the best position on the sheet. Draw a parallel line 1 inch from the top for the longitudinal seam; also draw lines parallel to the edges, front and rear 1 inch from the edge of the sheet for the fire-box seam rivets. The boiler card calls for fire-box rivets spaced 2½-inch pitch; measure off the length of the top rivet line, divide this length by 2¼, and obtain the nearest number of equal spaces and step off these spaces to suit. Now set the dividers for 2¼-inch space, start at the top rivet along the left-hand line and step off one space after another and see if the bottom rivet comes out far enough above the water-space frame to clear the head. This will rarely come out exactly right; we now either increase or decrease the space of the dividers and make another trial. This will be repeated until the last rivet comes exactly right. All the points will now be center-punched to suit the last spacing.

In a similar manner we lay out the rivets along the right-hand edge of the sheet as nearly 2¼-inch pitch as the even spacing of the rivets will allow. Draw two lines parallel to the lower edge of the mud-ring rivets. The drawing calls for thirty-seven equal spaces between the first through rivets in the corners. Measure off the length of this line, divide this distance by the number of spaces and get the pitch of the rivets. Set the dividers as near this distance as possible and run off a trial spacing; this will rarely come out right; with the slow-motion screw, increase or decrease the space and make another trial; finally this will come out exactly right and the rivets will be center-punched to suit the last spacing.

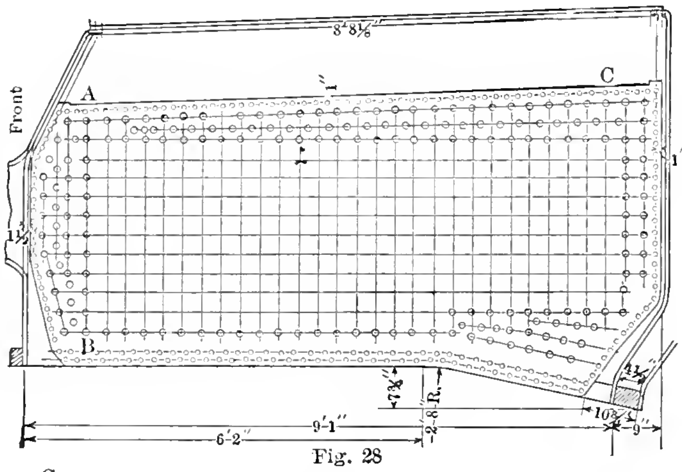


Fig. 28

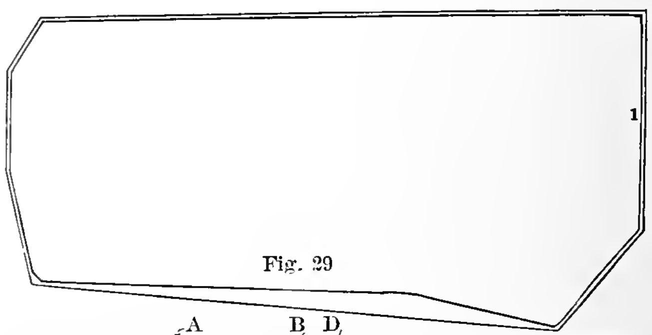


Fig. 29

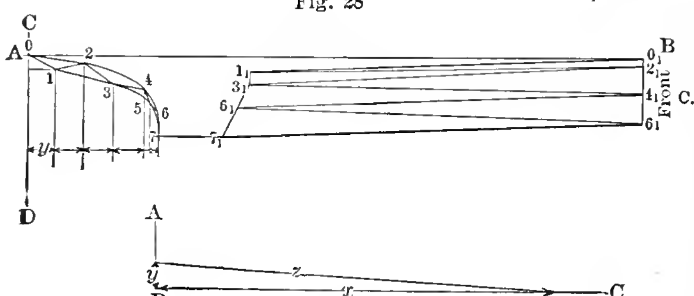


Fig. 30

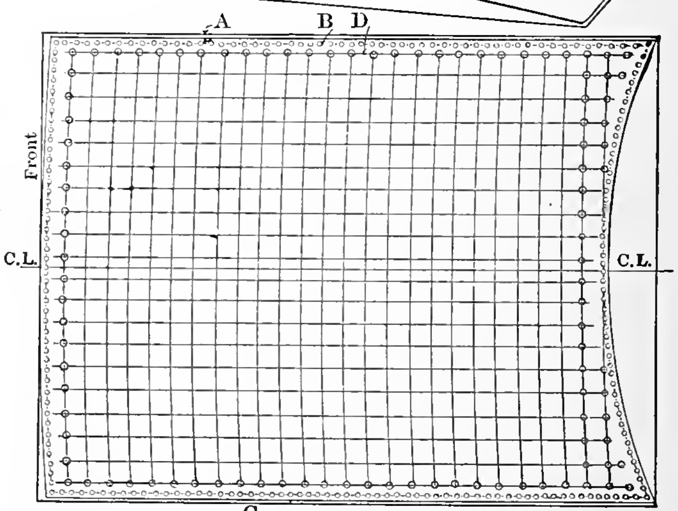


Fig. 31

Step off the second row of rivets half a space from these. The lines for the stay-bolts are not parallel, the spaces being wider at the front. Lay off from the figures on the boiler card, the distance front and back for the top line of stay-bolts. Draw this line the full length of the sheet. In a similar manner lay out the location of the second line, and so on. Sum up the overall length to see that you do not gain or lose, as the lower line must be a definite distance from the lower edge of the sheet. Too much care cannot be taken in laying out these lines, for there are often furnace bearers, pads, etc., required, and unless the rivets come exactly right these parts will not match up properly.

Beginning on the left-hand side of the sheet, draw the line

AB; this has a row of rivets all the way through. Then draw the line *CC*, divide the distance between these lines into twenty-seven equal spaces and draw parallel lines at right angles to the bottom line. The intersection of every vertical line with the longitudinal line gives the location of a stay-bolt. Lay out the rivets in the second row from the top as shown. The first rivet on the left begins on the diagonal center lines; the rivets are equally spaced; the last rivet coming on the extreme right hand. Now lay out the rivets in the lower right-hand corner and those on the left-hand end of the sheet to suit the figures on the card. All the work on this sheet should be thoroughly checked to make sure that everything is correct.

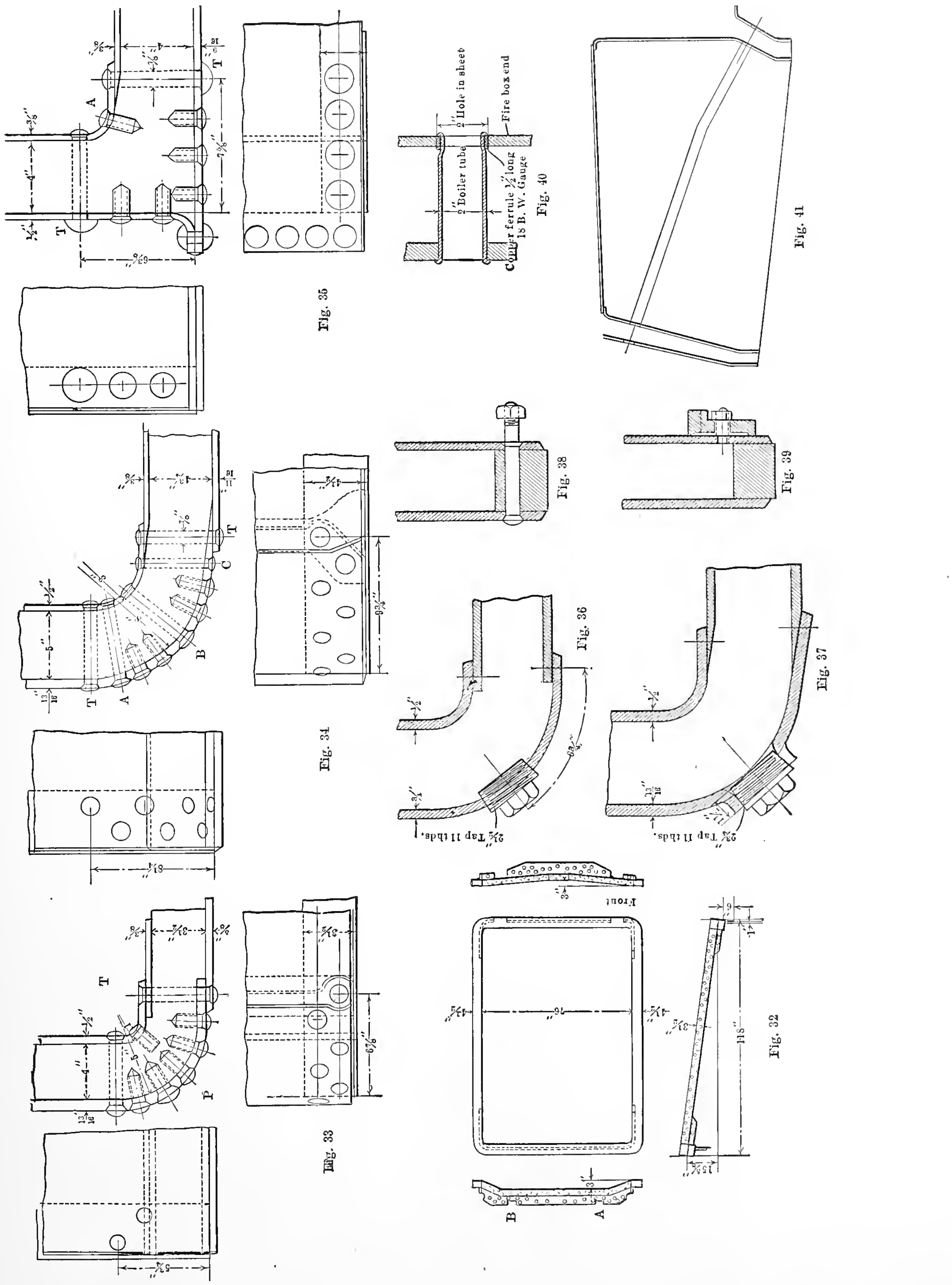


Fig. 35 Fig. 40 Fig. 41 Fig. 38 Fig. 39 Fig. 34 Fig. 36 Fig. 37 Fig. 33 Fig. 32

FIRE-BOX CROWN SHEET.

The crown sheet connecting the side sheet shown in Fig. 28 is represented in Fig. 30. The neutral line of the front and back of the sheet is shown in the left-hand view. Select a large sheet and draw a top reference line *AB*. At right angles to this, draw a center line *CD*. Lay out the two views of the crown sheet to the figures on the boiler card. Lay off on the front neutral line points 0_1, 2_1, 4_1, etc. Lay off on the back neutral line 1_1, 3_1, 5_1, 7_1. Connect these lines by diagonal lines in both views. Lay off the angle *ABC*. Lay off a distance *X* equal to the length of the ordinate *O*-1. Lay off a distance equal to the perpendicular height in the left-hand view. The diagonal *Z* is the true length of the first element. In a similar manner we get the length of each one of the elements.

We now make a layout on the plate which has been ordered for this crown sheet in a similar manner to that shown in Fig. 27. Strike off arcs with the radius equal to the length of the neutral line from one point to another, using the true length of the element as diagonal connecting lines. We thus obtain the length of this sheet as shown in Fig. 31. Draw the center line *CC* in such a position as to leave about ⅛ inch for planing at *A*. Draw the rivet center line along the right and left-hand side 1 inch from the edge. In a similar manner draw parallel lines 1 inch from the front and back edges. Now measure off the length of the rivet center line *B*, divide this by 2¼ and determine the nearest number of rivets; set the dividers as near the distance as possible and step these spaces off along the right-hand line. With the measuring sheet, get the length of the rivet center line on the rear end. Divide this by the pitch and get the number of equal spaces. Step these off to suit.

In a similar manner get the run of the front line of the sheet and lay off these rivets as nearly 2¼-inch pitch as possible. From the center line *CC* lay off a number of spaces corresponding with the figures for the stay-bolts for the front of the sheet. In a similar manner lay off figures corresponding to the figures for the rear end of the sheet. Draw straight lines through these points; measure up the overall, and if everything is correct, transfer these lines to the left-hand side of the sheet.

On a center line lay off 24 equal spaces 4 inches apart to suit the drawing. Also lay off these same spaces along the line C and D. Now bend the straight edge to take in the points on the center line and the two points *C* and *D*. While the straight edge is held in this position, run the pencil around and mark out this line. In a similar manner, draw all the other parallel lines. This gives the location of nearly all the stay-bolts in this sheet; the few extra holes at the rear end of the sheet will be laid out to suit.

MUD-RING.

The water space frame, or mud-ring, is frequently made of wrought iron. The design is made as simple as possible, in order to make a cheap forging. When the water space frame must be arranged with flanges and expensive off-sets, they are now being made of steel casting. The frame is machined all around the inside and the outside.

Fig. 32 shows a rather complicated frame. This is a steel casting, and these castings often come from the steel works considerably out of line. This frame must be strengthened, and oftentimes it is necessary to heat the frame in order to get it into line.

Lift the frame upon the surface plate, and block up one end to give the desired slope, and, with the surface gauge, level up the frame: now lay off the length 118 inches, and scribe a line across the top and bottom of the frame to which the ends must be machined. Now lay off the width of the frame inside 76 inches and the thickness of the sides 4½ inches, and scribe these four lines. Referring to detail drawing of the frames, lay out the radius for the corner inside. Then lay out the slope portion and the radius for the outside of the corner. This frame is now ready to have the corners milled and the sides planed. Before doing this, however, measure up the flanges, projections, etc., to be sure that the casting will hold up all around. After the casting comes from the planing machine, lay out two parallel lines on each side for the rivets. Step off twenty-seven equal spaces on the top line between the first through rivets; now step off the rivets in the lower row half a space from these. Lay out both sides of the frame exactly the same. Draw two parallel rivet lines on the front end, and step off nineteen equal spaces between the first two through rivets, also step off the lower row half a space from these. Lay off two lines on the back end and step off nineteen equal spaces. A number of holes are required on the flange portion for attaching the boiler to the ½-inch furnace bearer plates. With the surface gauge draw the lines for these holes. Lay out these holes to suit the figures on the detail drawings, also lay out the places *A* and *B*, as these plates are apt to come solid. In a similar manner lay out holes in the flange on the front end. Now lay out two holes on the flange at each corner; all these holes must be drilled. When more than one boiler is built from the same design a sheet-iron gauge is made by which these holes are all laid out.

WATER SPACE CORNERS.

Considerable difficulty is experienced in keeping tight joints around the corners of a water space frace. Various designs have been used with indifferent success. There are two designs of corners that are largely used; in the first the frame is milled out on the side and the throat sheets are set in with square corners, as in Fig. 33; in the second, the side sheet and the throat sheet are scarfed as in Fig. 34.

Frequently among builders of locomotives the boiler shop is supplied with corner cards; these give the details of the corners up to the first through rivets. Fig. 33 represents such a boiler-corner card. The patch bolts *P* are spaced around the corner at the outer circumference at about the same pitch as the through rivets. After the boiler is assembled, it is a rare thing that the corners will fit up nice and neat, therefore this must often be heated and pounded up tight against the frame. These holes are now laid off and drilled and tapped in position. The front tube sheet is pounded in close to the frame, and the hole *T* is laid off and tapped through the sheet into the frame.

Fig. 34 shows a corner where the side and the throat sheet are scarfed. The corner has a 3-inch radius on the inside; this enables the use of through rivets around the corner. *T* and *T* are the first through rivets that are run at right angles through the frame. *A*, *B* and *C* are through rivets, which hold the inside sheet close to the corner. After these sheets have been set into place, place a surface plate against the bottom of the frame, and with a surface gauge mark out the top and bottom rivet lines. Lay out these spaces to suit the figures on the corner card. The front and rear corners are in general very similar, except whatever change is necessary to accommodate the difference in width of the frame.

On the Wootten boiler the rear corner is different in shape, as shown in Fig. 35. *T* and *T* are the first through rivets, and are placed as near the corner as possible. The patch bolts are stepped off so as to maintain the same pitch as the through rivets, if possible. The bolt *A* is tapped through the sheet into the ring in order to make a tighter job around the corner. Too much care cannot be given to laying out and finishing the work on the corner, because if there is any possibility of a leak it is sure to be found near the corner.

In Fig. 36 is shown a corner plug. This is laid off 6¼ inches along the outer circumference of the sheet. Space this off either with the dividers or with a steel tape. This hole must be drilled and tapped for a 2½-inch taper tap. If the corner has a small radius, the threads are cut away so that you get but one or two full threads. In this case the sheet is often drifted out, as shown in Fig. 37. Lay off a hole to suit the location given on the drawing. The size of this hole must be obtained from shop experience in drifting out and upsetting the ends. A great deal depends upon the thickness of the plate, the radius of the corner and the size of the plug.

In addition to the regular through rivets in the water space frame, frequently special rivets are required which extend all the way through, and form the support for the grate. Fig. 47 shows such a bolt. In the layout these special bolts should be marked with a cross or circle on the sheet.

Fig. 39 shows another method which is often used to support the grate. The studs are laid off a certain distance up from the rivet center line. These holes can be laid off on the sheet and punched, as the side frames have elongated holes to take care of any variation in the casting; also in addition to the stay-bolts, air pipes, Fig. 40, are required. The holes are laid off on the diagonal lines between the stay-bolts, and they are usually punched with the rest of the holes and bored out with the drill to the dimensions given on the drawing. Many fire-boxes have tubes, as shown in Fig. 41; the holes are laid out the same way as in Fig. 40, except that the holes are larger than the tubes in the fire-box sheet and considerably larger on the outside sheet.

The drawing does not always show the details for these holes, and much is left to the judgment of the man who is laying out the work. Therefore, in settling on the size for these holes one must be sure that the tubes can be entered into place, rolled and beaded, and also that the tube can be removed in case a repair becomes necessary. The large holes in the outside sheet are to be plugged.

FIRE DOORS.

More care is necessary in laying out the fire door than is ordinarily supposed, as a lot of trouble will arise from a lack of good judgment.

Fig. 42 shows a rather simple fire door layout. *L* is the length of the neutral line along the curve. Lay off *M* equal to *L*, and get the diameter *D*, from this diameter must be taken a certain amount for trimming the sheet. This should not be less than ⅜ inch all around. Lay out the center lines of the fire door *BB* and *CC*, and strike a diameter that coincides with the one just decided upon. Where there are a number of boilers going through at the same time, these sheets may be punched out with a large special punch, otherwise the metal in the inside is removed by punching a series of ¾ or ⅞-inch holes all around the outside.

Fig. 43 shows another style of fire door. The holes in the outer sheet are laid out precisely the same as those shown in Fig. 42. The hole in the inner sheet depends upon the length of the stretch in making this hole. Usually where the flange is deep the sheet is heated, and it is stretched on the flanging press; afterwards the hole is laid out, depending in size altogether on the experience in flanging. This particular sheet is very difficult to flange in ⅜-inch stock when the flange is very deep, and more than one sheet has been lost in flanging. Fig. 44 shows another type of fire door opening. The oblong ring becomes worn with the firing tools, etc., and the opening is made in this way so that these parts can readily be renewed. The inner sheet is laid out in the same way as in Fig. 42. The outer sheet has a plain elongated hole in it. The angle is forged to required shape and welded. The holes in the leg of the angle which fit against the plate are marked off from this sheet. The other holes are laid out for the rivets through the ring. The inner ⅜-inch elongated sheet is bent up and welded along the seam. The holes on the flange of the inside sheet are marked off from this ring and punched to suit.

Fig. 45 is a style of fire door which is seen extensively on boilers of all sizes. This hole is laid out in exactly the same manner as Fig. 43, except that the hole is elliptical instead of circular. The holes are laid out in the flange of the fire-box back sheet and punched. The holes are marked off in the flange of the back head in position. These rivets must be hand-driven before the stay-bolts around the fire-box are put into place.

CHAPTER IV.

OUTSIDE FIRE-BOX SHEETS.

Various fire-box sheets have been laid out in a previous chapter, and now we come to those sheets which surround the fire-box, commonly known as the outside fire-box sheets. Some of these sheets are similar in a way to the inside fire-box sheet, but differ in many details. The back head and the throat sheet are flanged, and these sheets present by far the most difficult part of the work. The various sheets that will be shown presently are taken from a 67-inch Belpaire boiler which has been in operation, drawing the heaviest trains on one of the large Eastern railroads.

Fig. 46 shows a longitudinal section of the fire-box end of

this boiler, and Fig. 47 shows the cross-section of the same. It has been selected for several reasons. First, it has on it all the work which a much plainer boiler would have, and, secondly, in addition to this, it has a great deal of difficult work which one meets with on boilers which are out of the ordinary run.

THROAT SHEET.

The throat sheet on this boiler is shown in detail in Fig. 48. This sheet is usually ordered with liberal allowance for trimming. We will assume that the size of the sheet is correct, and with a straight edge draw the center line *CC*. This is done by striking off arcs from the corner with the trams as shown, and drawing the line *CC* to suit the position thus found. Lay off the line *D* to suit the boiler card, so that the corners at *E* have at least ⅜ inch for trimming. Measure off a distance 4 feet 6 1-16 inches from this line, and draw the center line *CC* of the boiler. From the center *K* strike a out the five bridges *N* as shown. All the metal is to be punched out along the circle except at these bridges. Make the bridges that remain about 2 inches wide. These are used for holding the sheet together when it is being flanged.

Measure off the distance *U* on the right-hand view, and lay off a distance *U* + ½ inch on the left-hand view. Also lay out a plan view of the lower part of the sheet and measure off the length of the neutral line *X*. Lay off the distance *X* + 1 inch as shown. In a similar manner lay off several intermediate sections and determine the length of *V* and *W*, and lay out *V* + ½ inch and *W* + ½ inch as shown. Through these points draw the outline of the sheet, thus completing the work until it comes from the flangers.

TOP THROAT SHEET.

The top throat sheet of this Belpaire boiler is represented in Fig. 49. *CC* is the center line. Strike off arcs from each

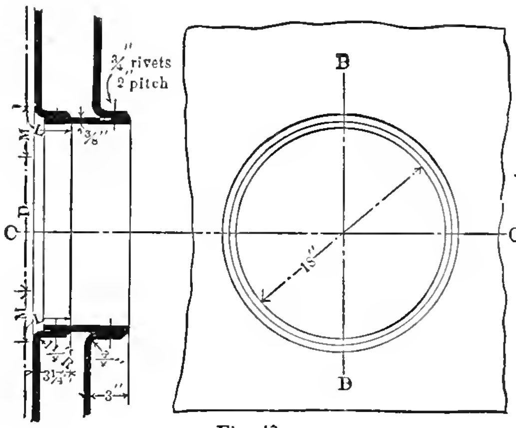


Fig. 42

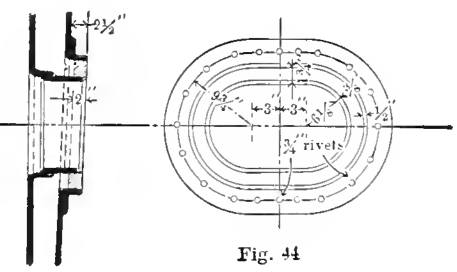


Fig. 44

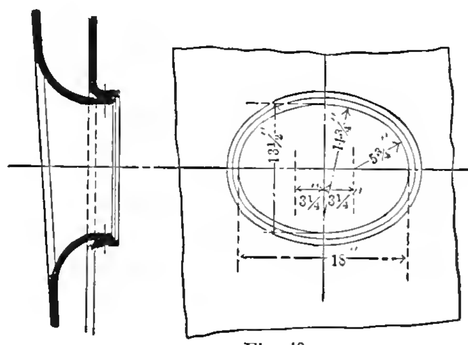


Fig. 43

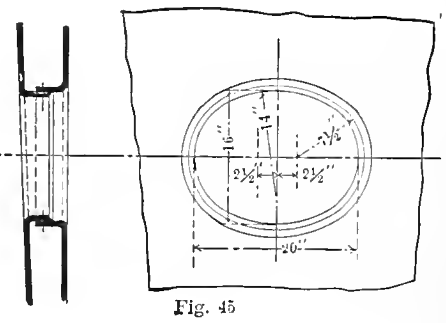


Fig. 45

circle with a radius of 3 feet ½ inch. Strike another circle ¾ inch outside of this, and draw the outside lines of the sheet as they would appear when flanged.

Now lay out the flat portion at *LL*, and draw the lines *M* and *M* to suit the dimensions on the boiler card. Also lay out the right hand view of Fig. 48. This can be done either on the throat sheet or on some other sheet. Measure off the distance *P* along the neutral line of the sheet. Now lay off this distance *P* + ½ inch, as shown along the center line *CC*. In a similar manner measure off the distance *R* on the right-hand view, then lay off a distance *R* + ½ inch, as shown on the left-hand view. Measure off the distance *S* and lay out the distance *T* in a central position. To get the length of *T*, take the average length of *S* and *R* + ½. Now find a radius which will pass through these points and strike a circle to suit. Draw another circle 1 inch from the inner edge of the flange, and lay side of the sheet at *E* and *E*, and draw the center line *DD*. Lay out the right-hand portion full size on the sheet, and measure off the length of the neutral line *A*. This distance is measured off from the straight line of the sheet around the curve to the end of the flange. Project the starting point on the left-hand view and lay off *A* + ½ inch. This flange has the same width all the way around. Draw the outline of the sheet all around, at this distance from the line of the sheet when flanged. In a similar manner we determine the neutral line *B* of the front flange. Lay off a distance *B* + ½-inch as shown. Strike a radius *R* from the limiting line of the inside of the sheet, also lay out the bridges 1, 2, 3, etc., to hold this sheet together while the outside is being flanged. In trimming off the extra metal around the outside, sheer close to the line at *G* around the corner, but allow a liberal margin, say, ½ inch, at all the other places. When the sheet is flanged the

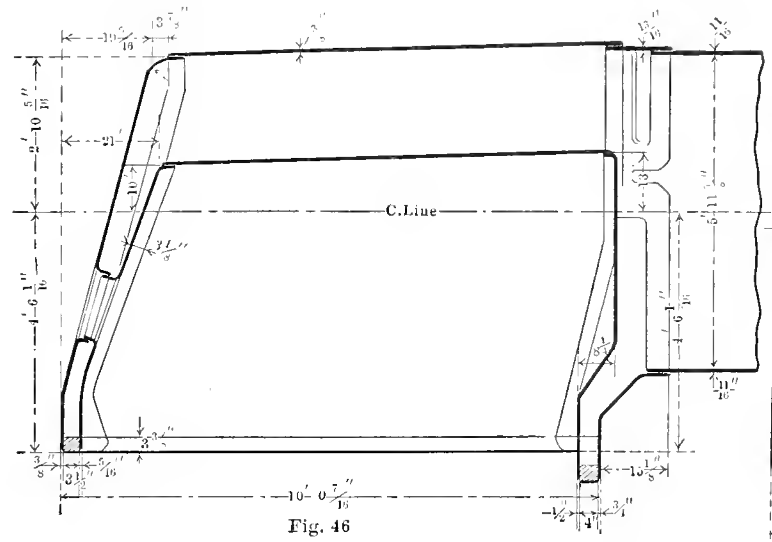


Fig. 46

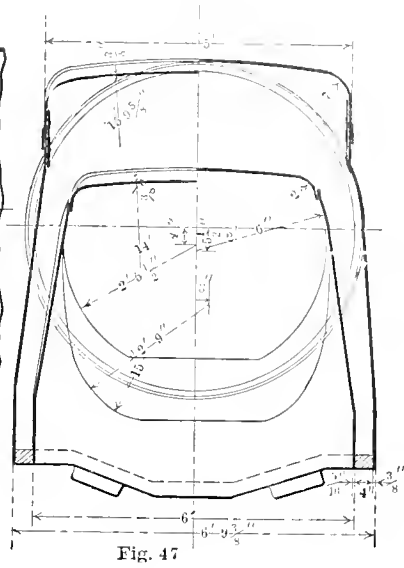


Fig. 47

metal will crowd around at G, so that we get more metal here than the flat sheet would indicate.

After this sheet comes back from being flanged, level it on the layout bench and measure it to see if it will hold up to drawing sizes all around. With the surface gauge, run around the outside and lay off the front and back line of the sheet. Frequently the drawing gives sufficient details to locate some of these rivets, but often this is left entirely to the layout man. In case nothing is specified, begin the front and back rivets on the top center, also settle on the location for the rivets on the bottom of the sheet. With a measuring wheel get the run of the boiler inside on the front between these extreme rivets. Punch this on the sheet, and see that the same checks up with the sheet, to which this top throat sheet is to be riveted. With the dividers lay off the desired number of rivets; all will be equally spaced unless otherwise specified.

BACK HEAD.

The back head of a locomotive boiler with a medium width fire-box is shown in Fig. 50. The flange is $5\frac{1}{4}$ inches deep

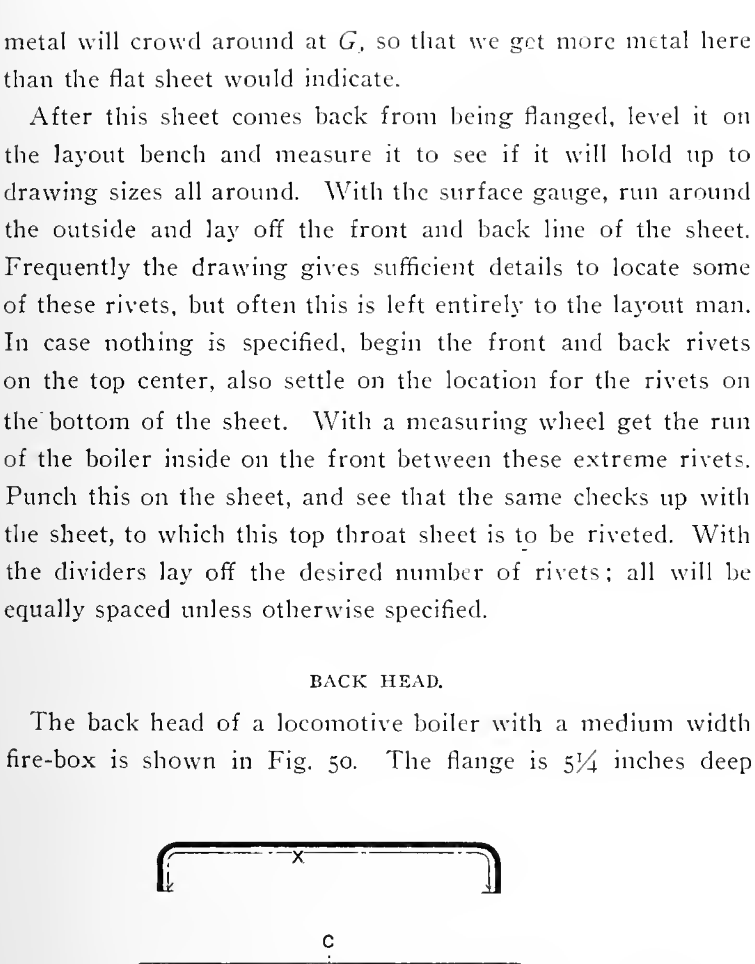


Fig. 48

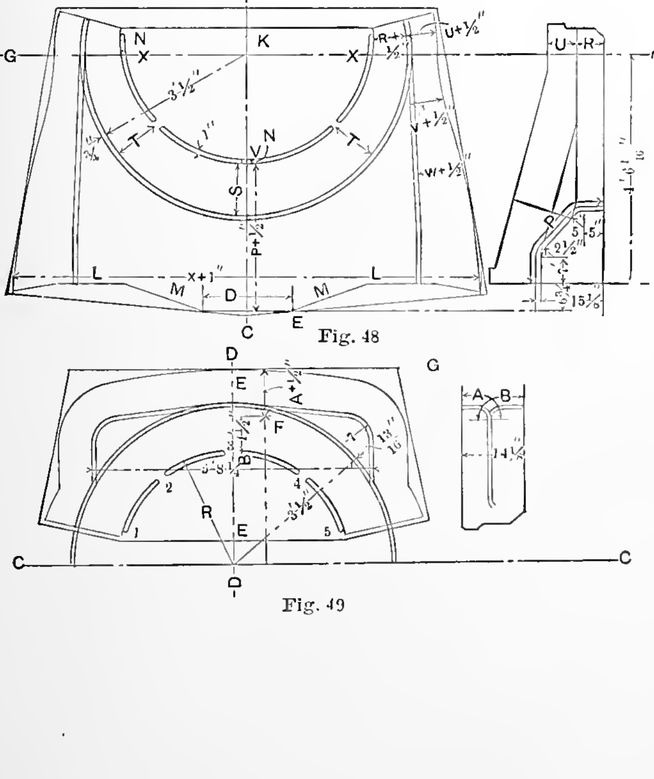


Fig. 49

and the plate is $\frac{1}{2}$ inch thick. The fire door is oval, and is flanged in. The connection for fire door to back fire-door sheet is made in such a way that the flange of the back head telescopes the flange of the fire-box sheet. The whole thing is riveted up similar to the fire-box sheet shown in Fig. 46.

Lay out the left-hand portion of Fig. 50, either on the sheet which has been ordered for this head or on a neighboring sheet, measure off a distance R along the neutral line of the sheet, after having laid out the center lines CC and DD. Strike the radius $R + \frac{1}{2}$ inch for the outline of the upper portion of this sheet. Lay off the distance A, which corresponds to the "out-to-out" distance of the head when flanged. Lay off a distance C on each side corresponding to B, and draw the limiting line of the sheet all around. Also measure down from the center line a distance $26\frac{3}{8}$ inches for the fire door. Measure off the distance E along the neutral line and lay off $E + \frac{1}{4}$ inch as shown; the distance G is central with the fire door. We can now measure off the distance K, which is necessary for forming this flange. With the dividers set to the distance K, strike off 10 or 12 arcs from the outline of the fire door and draw a smooth oval through these points. The oval hole GH must now be punched into the sheet, and the outline must either be chipped or milled smooth. The lower edge of this sheet must be planed off at a level for calking, also the sides M and M. The remainder of the metal must be trimmed away. The sheet is now ready to be flanged. Where the flange is short the majority of the holes for stay-bolts, rivets, etc., can be punched into the sheet before it is flanged. Those holes which come close to the curve and are liable to draw are put into the sheet after it is flanged.

The layout of this back head is shown in Fig. 51. The outline of the sheet and the fire door have already been settled on. Draw two parallel lines along the bottom of the sheet for the water space rivets. Measure off the distance to the first through rivets and step off the number of equal spaces called for on the drawing.

Measure up a distance $7\frac{1}{8}$ inches from the bottom and draw the line for the bottom row of stay-bolts. Measure off 2 inches for the first stay-bolt, and then step off 7 spaces each 4 inches as shown. Lay off the lines of holes one after the other. In laying out every second and third line sum up the figures

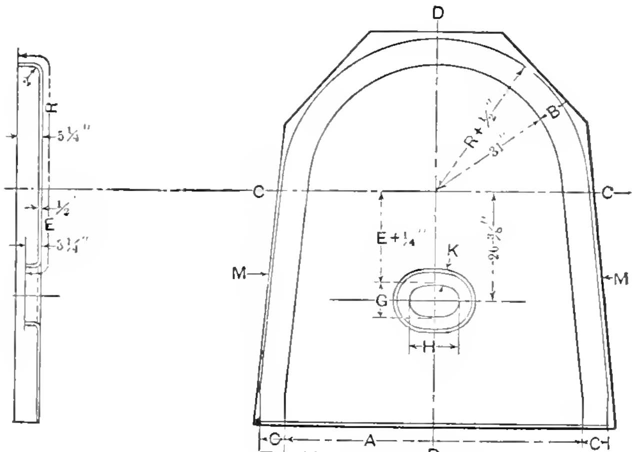


Fig. 50

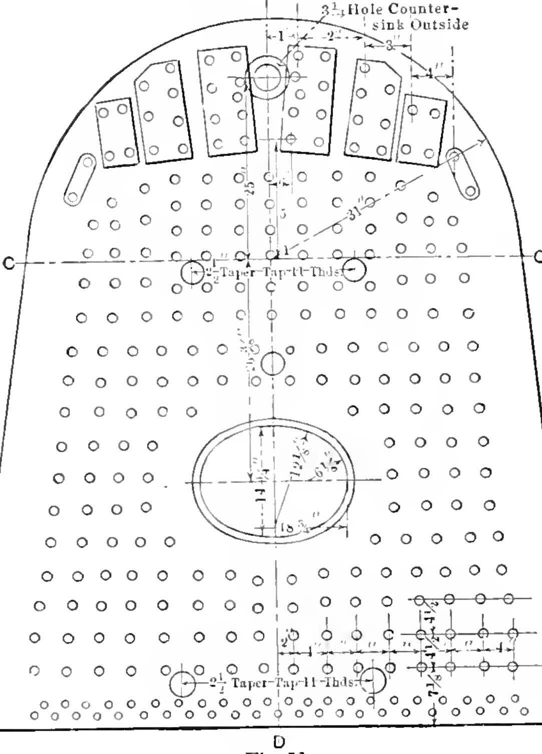


Fig. 51

from the bottom and measure off this over-all distance, to make sure that you are not gaining or losing. Three 2½-inch taper taps are called for, and are located on the center of the diagonal lines. Measure off a distance 25 inches from the center line, and strike a 3¼-inch hole for throttle connections. Lay out the four stud holes as shown. In laying out the rivet holes for the T-iron and crow-feet it is well to lay out the outline, as these pieces come very close in some instances, and when laid out full size there may be some interference of one part with another. The location of each group of rivets is given over from the center line *DD* and up from the center line *CC*. In laying out each one of these groups separately, where the dimensions are given at 1, 2, 3, etc., check the over-all dimensions to be sure that these are correct, for many times fittings, gauge cocks, etc., are laid out with small clearance for these stay-bolts. These connections are not shown on the boiler card, and therefore, if these rivets are not laid out carefully the layout man will be held to account when the boiler gets into the erecting shop.

SIDE SHEET.

The outside side sheet for the boiler shown in Fig. 46 is represented in Fig. 52. Hunt up the plate that has been ordered for this sheet and lay it on the bench with the side containing the maker's stamp, tensile strength, etc., up. Have another sheet underneath projecting a foot or so on each end. Clamp the sheets together in several places so they cannot slip. Draw the bottom line of the sheet, allowing about ⅛ inch for planing. From this line measure off vertically the distance to the center of the boiler, and draw the line *CC* parallel to the bottom line of the boiler.

Lay out the left-hand portion of this sheet. It will be noted that the taper will be 6 3-16 inches. The left-hand view gives the shape of the sheet at the front and back. Make the construction for the back head and throat sheet to the figures as shown. Draw the inside line of the flange of the back head and measure off a distance 3 9-16 inches from this line, and draw the back slope line of the sheet. In a similar manner draw the back straight line of the sheet. Also draw the back line of the throat sheet, and lay off the back slope line and straight line of the sheet at 3 9-16 inches from the line of the flange. The dimensions *A* and *B* are obtained from the drawing, and must be measured off around the neutral line of the sheet, as shown on the left-hand view.

The outline of the sheet has now been mapped out. Draw two parallel lines along the lower edge for the water space rivets and step off the desired number of equal spaces. Draw two parallel lines along the back and step off a number of equal spaces as near the pitch called for as possible. In a similar manner lay out the top row of rivets and the two rows of rivets along the front edge. Begin to lay out the stay-bolts by drawing the lower line parallel to the bottom line of the sheet. The first hole is 9⅝ inches from the back of the water space frame, and the front holes 2⅛ inches from the rivet center line as shown. All the holes below the lines *EE* and *FF* are equally spaced lengthwise of the boiler. The other holes are laid out to suit the figures on the drawing. Lay out the next line of holes and mark off the holes from the first line. Also note that the lines for rivet holes are parallel vertically but not horizontally. Each line must be laid out to suit the dimensions given, and these dimensions should be laid out along the left-hand view. The holes at *X* are for the long stay-bolts, which are run through the boiler and stay the upper square corners of the Belpaire boiler. The sheet will be bent to shape in the bending rolls.

FIRE-BOX CROWN SHEET.

Fig. 53 shows the fire-box crown sheet. It is 5 feet 9 inches over-all in width. The radius in the corners is 7 inches, and the length of the sheet along the slope is 8 feet 6⅛ inches. Fig. 54 gives the outline of this sheet. This we lay out by the triangular method shown in a previous issue. Having settled on the outline of the sheet, we draw two lines along the side 4¼ inches from the rivet center lines; also draw two lines parallel to the edges, front and back, 1⅛ and 1¼ inches as shown. Draw the center line *CC* and lay out the outline of the group of holes as shown.

Draw the parallel lines for the stay-bolt holes to the dimensions given. Mark out all these holes and then lay off the four wash-out plug holes, and strike a circle to correspond with the tap called for. These holes must be drilled a special

diameter as they come on the curve, and when the sheet is bent the outside will open up. Therefore, care must be taken to have sufficient metal so as to have full threads.

STAYING FIRE-BOX SHEETS.

The layout of the inside and outside fire-box sheets has now been given, but nothing has been said in regard to the connections and details of these sheets. There are many methods of staying the various sheets of a locomotive boiler, and a number of the methods which are in common use will be shown.

Not all the surfaces of the locomotive boiler need to be stayed. The outside cylindrical sheets will keep their shape

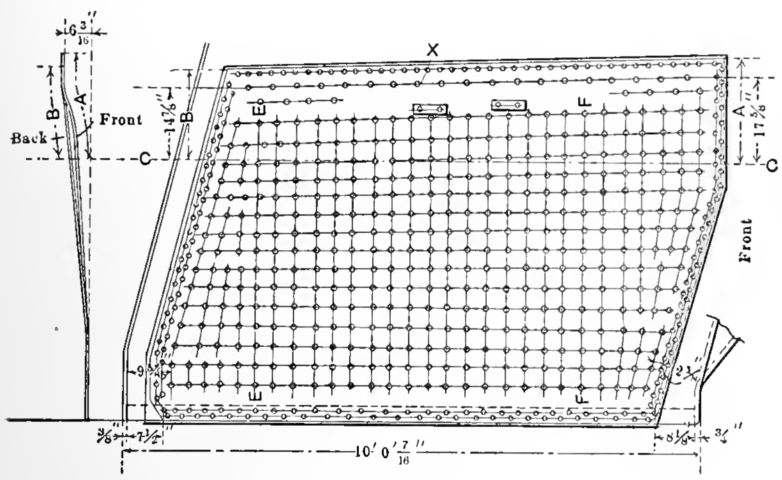


FIG. 52.

without staying. Side cylindrical sheets with a pressure acting all around must usually be stayed, as these sheets are apt to collapse. This is not always true, however, especially when the cylinder is small. But when the cylinder is of large diameter some method must be used to prevent it from collapsing.

The Morison corrugated boiler needs no staying. The method of staying determines the different varieties of boilers. The Belpaire boiler is rendered simple from a standpoint of staying for the reason that all crown stays are radial or pass through the sheet at right angles to it. The head on the stay can be formed up to much better advantage, as the nut and washer bear evenly all around. This radial staying is different from that which must be employed in the common form of locomotive main fire-box, for the reason that these stays pass through the outer shell at an angle and must be riveted over cold, in place. Such renewals are not easily made. All the stays which have just been mentioned are round stays. The front and back head are often stayed with plates, bar iron, and numerous patented shaped braces, as the Huston, McGregor, etc.

Fig. 55 shows the common form of stay-bolt which is used around the fire-box. These stays are machined in standard lengths, varying by ½ inch for short stays and several inches for long stays. They are turned down in the center at *A* or else upset from rough bar iron at a diameter equal to *A* so as to give the necessary thread on each end. In Fig. 56 is illustrated one of these stays just after it has been screwed into place. It is nicked at *N* by hand and is then broken off, or is then clipped off with pneumatic stay-bolt clipper. The stay-bolt is cut off inside and outside, leaving sufficient metal for riveting over. The safety hole is drilled in the center, as shown in Fig. 55.

The six central rows of crown stays are nearly all made radial to the crown sheet. Fig. 57 shows this stay. It is 1⅛ inches at the threaded part and 15-16 inch in the center. These stays are headed up in the bolt machine and are usually gotten out to suit the boiler for which they are intended, and thus vary but little in length from what is actually required. This stay must have a 3-32-inch fillet on the inside of the inside sheet and on the outside of the outside sheet. The threads are V shaped, 12 threads per inch, and the holes in the sheet must be tapped so as to give a full thread. In punching the

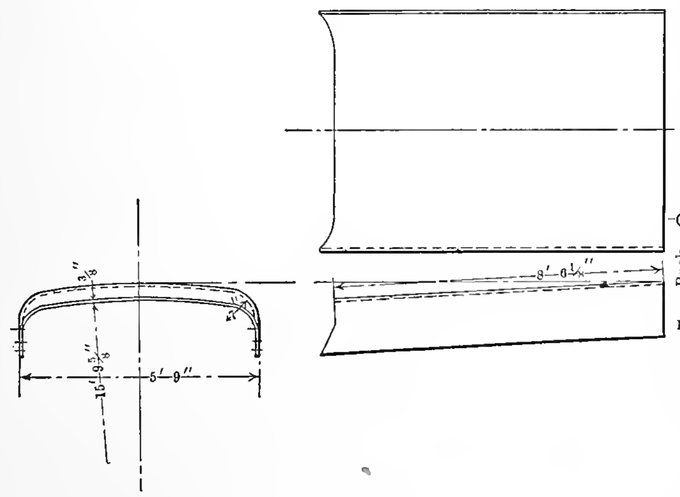


FIG. 53.

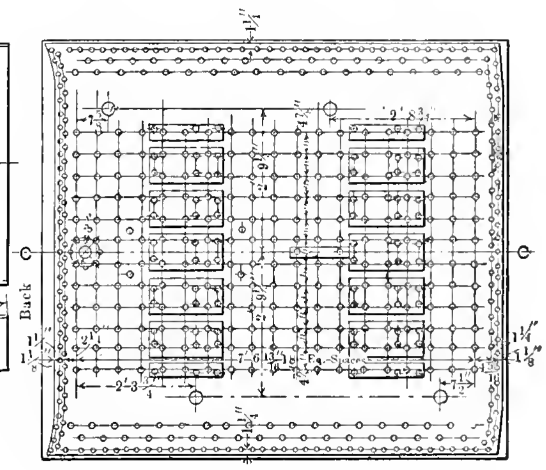


FIG. 54.

sheets, care must be taken that the holes are punched small. When these are reamed out and tapped, we should have a full thread all the way through the hole. It is often the case that these holes are scrimmed on and not enough time is spent in reaming them and forming good threads.

After the radial stay is screwed into place and every bit of slack is taken up, it is riveted over on the outside and finally brought down to the shape specified. Another style of stay is shown in Fig. 58. The crown stays of many boilers are made this way throughout. The heads *H* and *K* are all standard size and are made up under the hammer in large quantities. They are threaded, screwed into place and riveted over the same as the regular stay. Where these stays pass through the sheet at an angle, care should be taken in reaming and tapping so as to bring the center line of the link and head in

one line, otherwise there is a bad pull sideways which will break off the head just where the head portion enters the lathe or in the pipe machine, in order that we can be sure of getting a square bearing all around.

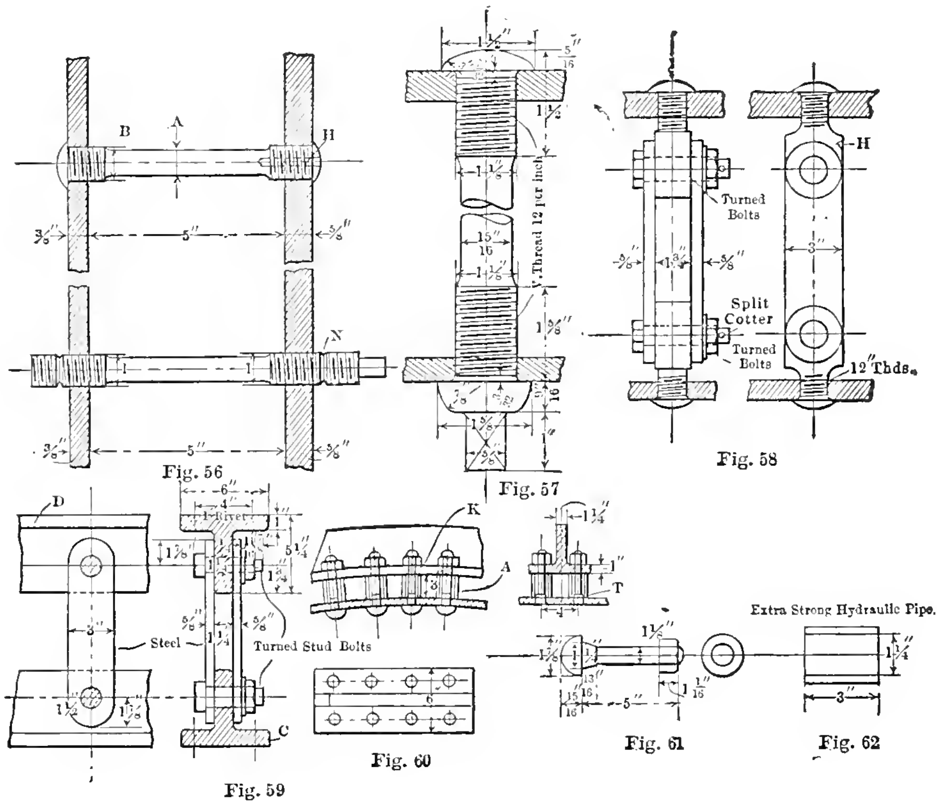


Fig. 56 Fig. 57 Fig. 58 Fig. 59 Fig. 60 Fig. 61 Fig. 62

sheet. The holes in the head and link are reamed and the bolts should be turned to a nice fit.

Another method, which is commonly known as the sling stay, is represented in Fig. 59. *C* is the crown bar which is bent to the curvature of the crown sheet, and is bolted to it at a fixed distance of 3 or 4 inches from it. The T-iron *D* is bent to fit the outside shell of the boiler and is riveted to it with common button-head rivets. The holes through the T-iron and links are reamed, and the bolts should be turned to make a neat fit.

In assembling, the T-iron is bent approximately to fit the curvature of the boiler. It is then taken and tried in place. It must be bent one way or another so as to conform neatly with the lines of the boiler. The holes are marked off from the boiler shell and are drilled to suit. The T-iron on the shell of the boiler is riveted in place with a hydraulic machine. The T-iron *C* is attached to the crown sheet as illustrated in Fig. 60. This T-iron is a heavy section 6 by 1 inch on the bottom flange and 1¼-inch web. *T* is a taper portion through which the crown sheet and the bolt is entered into place, so that the head bears up tight all around. The thimbles *A* are cut off from extra heavy hydraulic pipe, and the ends should be square and free from fins. The holes *K* are drilled 1-16 to ⅛ inch larger than the bolt. Put in the outside bolts first, but do not draw these up until the thimbles and other bolts are put in place. Screw up all the bolts tight, and then take out every bit of slack with a hammer and go all over the nuts and tighten them up again.

Fig. 61 gives a detail of the bolt, which is 1⅛ inch in diameter in the nut. It is 5 7-16 inches long. The head must be faced off true where this rests against the sheet and the nut must be faced off on the bottom. Fig. 62 shows an extra heavy hydraulic pipe. These should be cut off either in the

CHAPTER IV.

BRACING THE CROWN SHEET.

The flat crown sheets are often stayed as shown in Fig. 63, where the entire load is taken up on the side sheets. The bars *B* must be forged approximately right and then shaped and filled to fit exactly in place. At least 3 inches is allowed for the circulation of the water.

The long through stays of the Belpaire boiler are shown in Fig. 63a. They are 1⅛ inches in the body and 1 5-16 inches tap. They are screwed into place with a pipe wrench. A washer *W* is placed against the sheet and a nut *N* pulled up tight against it. This is used when the sides of the sheet are parallel.

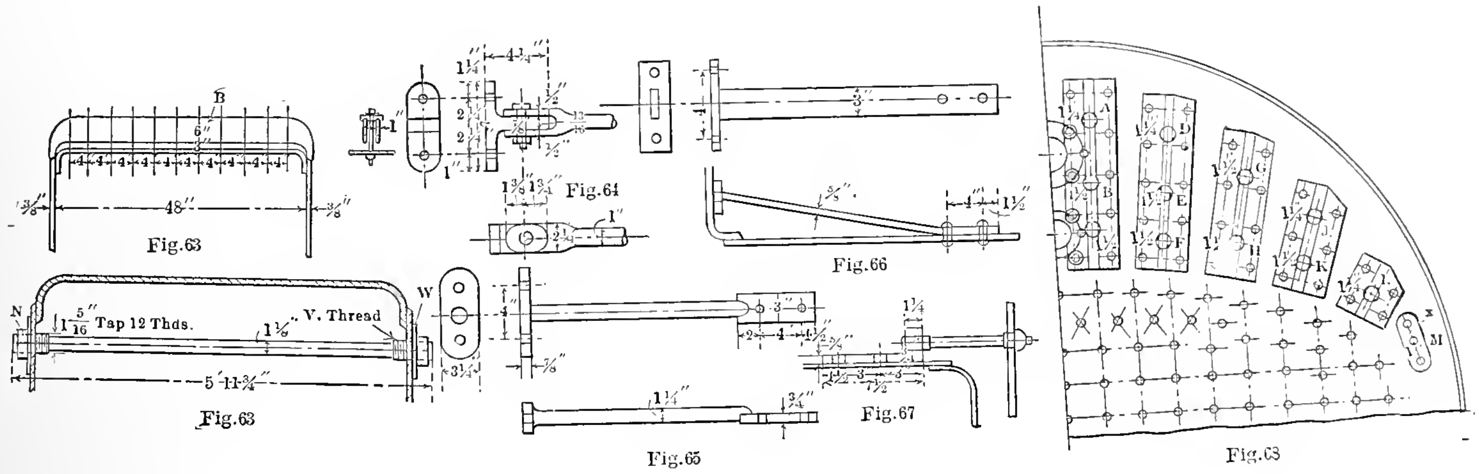
Thus far nothing has been said in regard to staying the front tube sheet and the back head. The method commonly used is to rivet the section of the T iron to the head and then stay the T iron to the sides of the boiler. Where the T iron does not work in to good advantage, several different kinds of crow feet are used. These are made to standard sizes and made up in large quantities and are kept in stock.

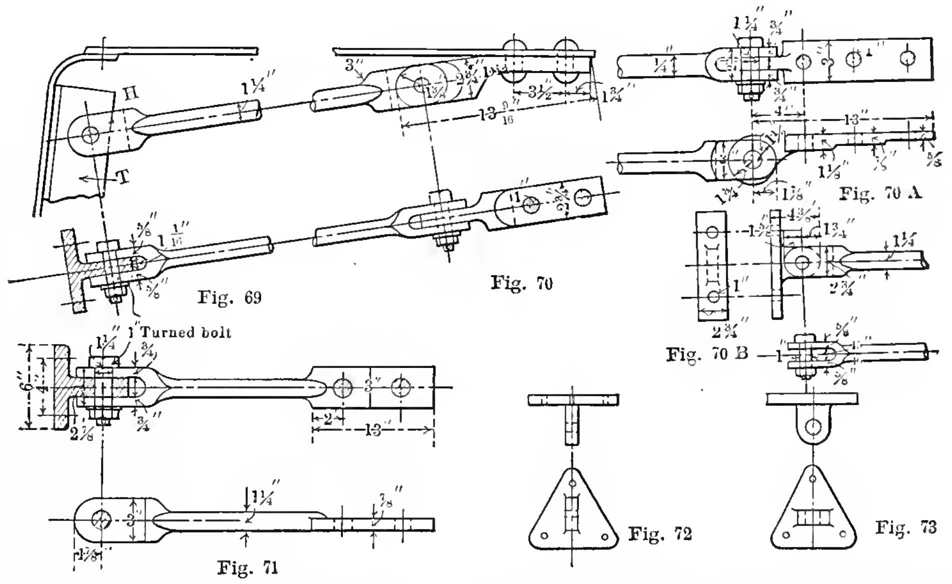
Fig. 64 shows a two-rivet foot for a 1-inch stay-rod. This style is used largely for staying around the outer curve of the back head, and is used for staying the throat sheet, around the curve where the sheet is attached to the dome course.

In Fig. 65 is illustrated a stay-rod which is used for staying the outer shell to the back head. It is convenient, as one can run this stay around at an angle and reach places which could not be stayed with through stays. This stay is also made as shown in Fig. 66. This often works in to better advantage than either of the stays just mentioned. This is especially true around the outside of the Wooten boiler, where the sur-

face runs at right angles to the line of the stays. In staying the back tube sheet, there is a section which cannot be reached with the tubes nor with the regular stay-bolts, therefore a line of special through stays must be used.

A throat stay which is used largely for this purpose is shown in Fig. 67. This stay-bolt is screwed through the sheet into the foot. The foot is riveted to the side of the boiler with two button-head rivets. Care must be taken in laying out the holes on this course to suit the number of stays required. This figure calls for 3 inches center to center of rivets. The holes are punched into the sheet and drilled into the foot by jigs. There should be no difficulty in getting these holes to match up properly when they are ready to be





riveted into place. Numerous other devices are used for staying the throat sheet at this point. In some instances the stay shown in Fig. 66 is used. The foot is riveted to the back tube sheet with an extra heavy pipe furrow between to allow for a free circulation of water. Still other stays are used where the main body is a flat bar and the end is forged into a round head. Into this head is fastened the rivet which passes through the tube sheet. The main part of the staying of the front tube sheet and the back head is done either by means of heavy T iron or else by plate gusset stays.

A good example of T-iron staying is shown in Fig. 68. The rivets are laid out in groups 4 inches center to center one way, and 4 inches to 5 inches center to center the other way. *A, B, C* show the places at which the stay-rods are attached. At *X* is shown a two-rivet stay which works in to excellent advantage. These T irons are stayed to the side of the boiler with rods which vary in diameter from 1 inch to 1½ inches.

Fig. 69 shows a 1¼-inch rod. The head *H* of these rods is made in proportion to the body of the rod, so as to give a uniform strength throughout. Also, the diameter of the rod varies with the diameter and number of rivets which the rod must support, and the diameter of the bolt must be made in keeping with the strength of the rod. In some shops these things are all nicely worked out and good drawings are at hand for these details; but in other shops they depend entirely upon the good judgment of the boiler maker. In this case, the boiler maker must be careful that he does not get one part too weak for another. The T-iron sections are made of different weight, depending on the boiler pressure and the size of the surface to be stayed.

The stay-rods must be swung out radially against the sides of the boiler. The rod *D*, Fig. 68, would be quite short, while *F* would be a very long rod, and would extend back and would probably be attached to the dome course. Here, again, this matter of locating the stay-rod is left to the boiler maker. In laying out the various courses, therefore, the location of the foot for these stay-rods must be settled on. Also, care must be taken in locating these feet, as there are a number of things that this rod could interfere with.

In Fig. 70 is shown the construction of a stay-rod and foot which is largely used. This shows the connection of the rod

to the foot and the method of attaching the foot to the boiler. Two 1-inch rivets are required for a 1¼-inch rod. Fig. 70a shows an excellent end with three rivets instead of two, used where the stay-rod is short, and the angle which this rod makes with the side of the boiler is small; the foot is made solid, as shown in Fig. 71. The section of T iron shown in this figure is a very heavy one, and the jaw for this 1¼-inch rod is made wide enough to take in the flange, which is 1⅜ inches thick. The turned bolt is 1¼ inches in diameter. This is often used for the top stay-rod, as shown in *A, D, G*, etc., Fig. 68. The arrangement of a 1¼-inch rod with a two-rivet foot is illustrated in Fig. 72. This would be used when the rod is swung out radially against the side of the boiler.

Figs. 72 and 73 show two styles of three-rivet crow feet. By using one of these crow feet, it is possible to stay a large surface to excellent advantage. In fact, some boilers have been built where nearly the whole of the stayed surface of the front tube sheet and back head have been stayed with one or the other or both of these two styles of crow feet.

In all of the staying which has just been described, bars are used for taking up the pull. There is another method of

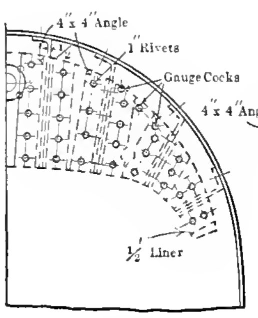


Fig. 74

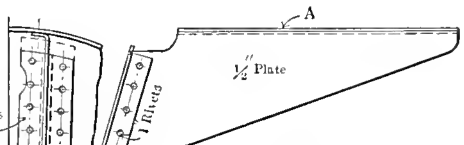


Fig. 75

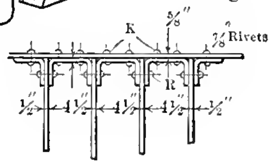


Fig. 76

staying which is held in high esteem by many engineers and boiler makers. This consists in using gusset plates instead of bars. This method of staying works in to excellent advantage on the back head of Belpaire boilers. The plates are riveted to angle-irons and angle-plates, and these in turn are riveted to the shell and surface to be stayed. Large holes are then punched through these gusset plates to clear the large through stay-rods which pass through the top of the boiler.

Fig. 74 affords a good example of such staying. A ½-inch liner is used for stiffening up the back head; 4-inch by 4-inch angles are riveted to the back head and to the gusset plates. These plates are ½ inch thick and are bent over on top so that they can be riveted to the shell of the boiler.

The angle-irons are riveted to the gusset plates and then each one of these gusset sections is riveted into place separately. One of these gusset sheets which are used for staying the back head is shown in Fig. 75. The spacing of these rivets is usually shown on the drawing and is not left to the judgment of the layer-out. The boiler card gives the location of the rivets along the top line *A*; these must be laid out on the shell together with the crown stay, and the holes are to be punched to suit. In using this method of staying on a Belpaire boiler, the part *A* is attached to the outer shell of the boiler in several different ways. These gusset plates are all vertical and are all attached to the outer shell along parallel lines. A U-shaped sheet is bent so as to fit in between these vertical plates. Another U-shaped piece is entered in between the next set of plates, as shown in Fig. 76. The plates are fastened to the U-shaped piece by rivets *R*, and these pieces are fastened to the shell by rivets *K*. This whole arrangement makes a very rigid method of staying, but is not so easily repaired as some of the other methods that have been shown.

SMOKE-BOX.

The smoke-box of a 74-inch Belpaire boiler is illustrated in Fig. 77. *R* is a ring, uniting the first course with the smoke-box sheet, and also used for making connections to the front tube sheet. The smoke-box sheet is usually ½ inch thick for the average boiler. While this sheet is thick enough to serve its purpose as a smoke-box, it is too thin to be bolted directly to the cylinders. The sheet would bend, and the whole thing would be too flimsy. Therefore, this sheet is nearly always reinforced with a smoke-box liner. These liners vary in thickness from ⅜ to ⅝ inch, and in some cases, which will be shown presently, they are made up of plates which are considerably thicker than this.

The cylinder opening *D* must be made large enough to take in the flange of the cylinder. The size varies with the arrangement of the steam pipe and exhaust pipe connections. The size of the opening is usually given on the drawing; when it is not given the layer-out should make a full sized layout of the cross-section of the boiler through the cylinder flange. From this layout and the boiler card the opening can be readily determined upon. On this same layout the cylinder bolts should be laid down as well as the cylinder flange. Any rivets which would be put through the smoke-box sheet and liner will have to clear the cylinder bolts by a reasonable amount. Any rivets which would come underneath the cylinder flange would have to be countersunk so as to clear the casting.

In reference to the cylinder bolt, there are in general two methods used for putting these holes into the sheets, depending upon the different boiler shops. First, these holes are laid out on a flat sheet and then punched, and finally when the cylinder is chipped to fit the boiler and the boiler is entered into place, these holes are reamed out to size. Second, when the layout of the flat sheet is made, the cylinder bolt holes are laid out so as to be sure that there will be no interference with rivets which might be put through the sheet to hold the liner. The cylinder-bolt holes are not punched. The cylinder is chipped and the boiler is lowered into place. The bolt holes are then drilled through the sheet, using the holes in the cylinder flange to guide the drill.

The layout of a smoke-box sheet, as it appears before being bent, is represented in Fig. 78. Draw a line along the top, allowing sufficient metal for planing, and measure off a distance of 43 inches, at each end of the sheet, and with a straight edge draw the bottom line. Mark one side of the sheet, front, and mark the right and the left-hand side as shown, measure off a distance 20½ inches from the front line, and draw the cylinder center line *DD*. Look up in the table of circumferences and get the circumference corresponding to the neutral

diameter of the sheet. The drawing calls for 74 inches outside diameter. The neutral diameter, therefore, is 72½ inches, and the circumference corresponding to this is 230.908 inches. Lay out this distance along the line *DD*. Draw the end line at right-angles to *DD;* bisect this distance and draw the bottom center line *CC;* bisect each one of these halves and draw the right-side center line *FF* and the left-side center line *EE*, and draw the two front rivet center lines. The drawing calls for forty-eight ¾-inch rivets; this gives twelve rivets in each quarter. Begin the rivets on the top center line, making twelve equal spaces as shown. Begin the front row of rivets on the top center line, and step off twelve equal spaces in each quarter. Step off the rivets in the second row a half a space from these.

The drawing calls for a cylinder opening 15 inches by 2 feet 3 inches. This is laid off symmetrically with the cylinder center line *DD*. Also lay out the smoke-stack hole with 11-inch radius. Lay off four bridges as shown, and mark the rest of the metal to be punched away. Now begin on one side of the bottom center line and lay out one line of the cylinder bolt holes after another, until all these holes are laid out on one side, then transfer this layout to the opposite side. Also lay out a line of rivets on each side of the center line *CC* for attaching a ½-inch liner. This smoke-box has an extension, and, therefore, we will not require any holes for the cleaning pipe connections. A line of rivets must, however, be laid out on each end for riveting up the top seam, and these are laid out as shown.

The smoke-box liner is laid out complete in Fig. 79. The holes for the cylinder bolts are 1⅛ inches in diameter, and must be reamed to size. In order to lay out these holes on the flat sheet, it will be necessary to make a full-size layout of the front end of the boiler. The cylinder flange and all the bolt centers will be laid out as in Fig. 80. The dimensions, 4¼, 4½, etc., are measured along the outer circumference of the smoke-box sheet *B*. With the trams draw the neutral line of the liner, beginning on the center line *CC*, and with a measuring wheel run along the neutral line and mark off between the center lines the distance corresponding to this measurement. Begin on the center line *CC* and run over the neutral line *D*, and get the total measurement to the extreme rivet center line *E*. Add up the intermediate dimensions and see whether they check with this over-all measurement. Make whatever alterations that are necessary in these intermediate figures and then the holes can be laid out on the flat sheet. In marking the size of holes on the layout for the cylinder bolts, be sure that they are punched small enough to allow for some variation in the holes when the parts are assembled. When these holes are reamed out we should have a clean, straight hole.

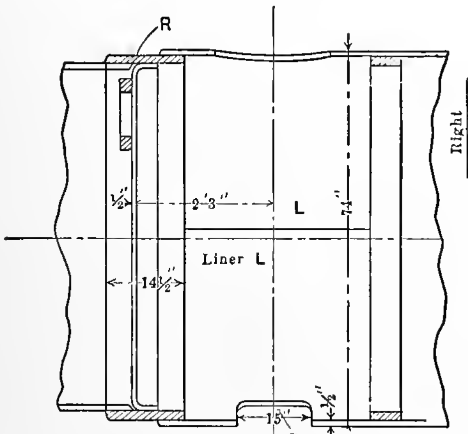


Fig. 77

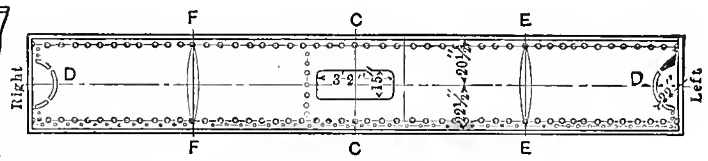


Fig. 78

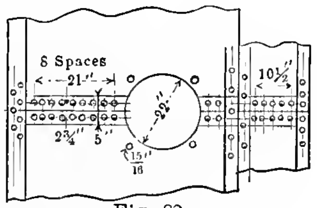


Fig. 82

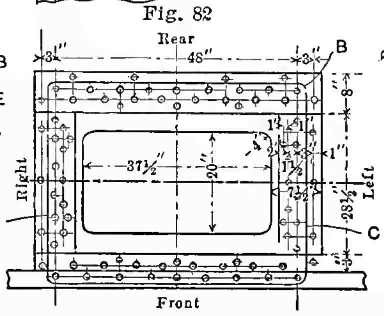


Fig. 81

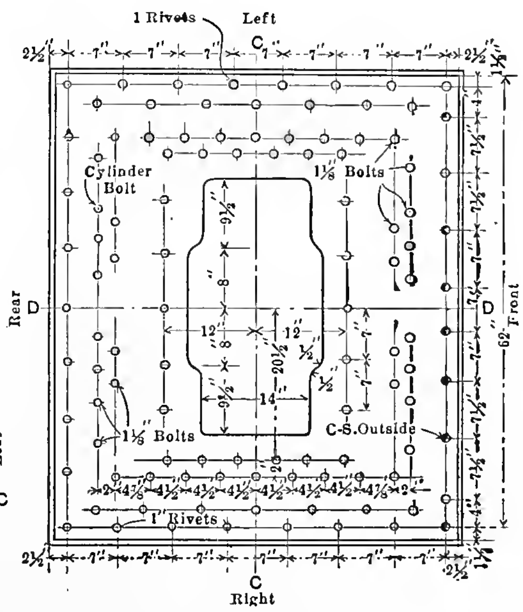


Fig. 79

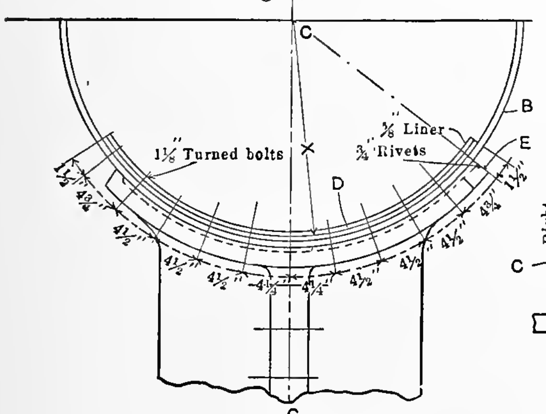


Fig. 80

The smoke-box liner shown in Fig. 79 is taken from a 70-inch boiler. The first course extends on through by the tube sheet, and the smoke-box sheet is riveted to it. A ring, 4½ by 1½ inches thick, being used between the two courses, where they are telescoped over each other, the liner butts up against this intermediate ring and butts up against the smoke-box front ring in the front. Draw the rear line along the edge of the sheet, allowing sufficient metal for planing. Measure off a distance 53½ inches at each end of the sheet, and draw the front line of the sheet. Measure off from the front line 27 inches at each end of the sheet, and draw the cylinder center line *CC;* note that this is not the center line of the sheet, as there is 26½ inches from the center line to the back line of the sheet. Measure off along the center line a distance 62

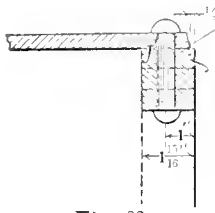


Fig. 83

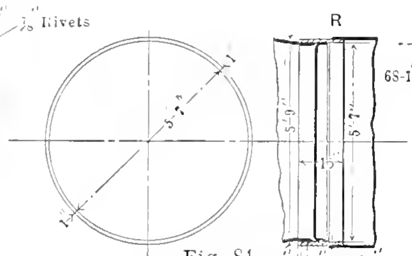


Fig. 84

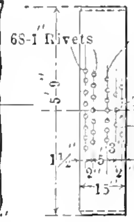


Fig. 85

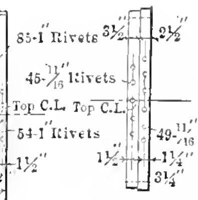


Fig. 86


Fig. 87

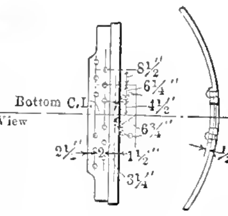


Fig. 88

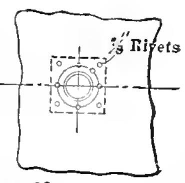


Fig. 89

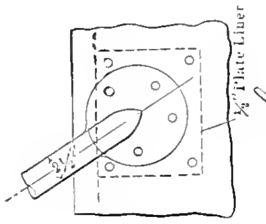


Fig. 90

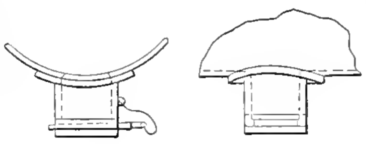


Fig. 91

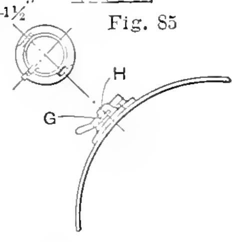


Fig. 92

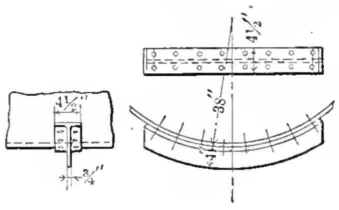


Fig. 93

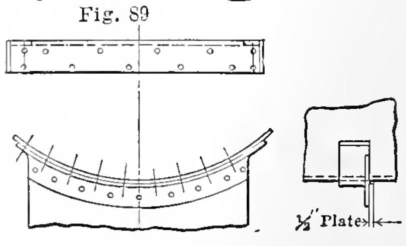


Fig. 94

inches for the length of the sheet; square up the end of the sheet and draw the center line *DD* at right angles to the cylinder center line. First, we lay out the cylinder opening; this is 41 inches long and 19 inches wide at the center, and 14 inches wide at the ends. It will be remembered that the dimensions, which are given in these illustrations, are to be measured on the outer circumference of the smoke-box sheet. These dimensions would, therefore, be varied somewhat, depending upon the full-size layout which would be made for this boiler, and would be similar to Fig. 80. The longitudinal dimensions would be laid out exactly like the figures given. Mark all cylinder bolts with a dash of paint or circle, according to the practice of the shop. Draw the front and rear center line 2¼ inches from the edge, and lay out these rivets in accordance with the dimensions which have already been settled upon. Draw the left and right center line parallel to the edge at a distance from the center line *DD*, corresponding with the measurement obtained with the wheel along the neutral line of the sheet. We now lay out these rivets, which will be equally spaced 7 inches apart. The necessity of strengthening the smoke-box where it is attached to the cylinder has been mentioned. The liner which has just been shown is ⅝ inch thick; but these liners have been made three-fourths of an inch in some boilers, in order to get the desired stiffness.

In Fig. 81 is shown a method for stiffening up this part of the boiler for a smoke-box which is 81 inches outside diameter. The cylinder bolts pass through the shell and through stiffening bars *B*. These bars are 1⅛ inches thick, and are made wide enough to take in the cylinder bolts and a few extra ⅞-inch rivets. The dotted line *C* shows the outline of the cylinder flange. These bars are too heavy to be punched, and, therefore, these holes will be laid out in the smoke-box sheet in a similar manner to that shown in the smoke-box liner. These bars are then bent in the bending rolls to conform to the proper diameter. The holes are then marked off from the smoke-box sheet and drilled to suit. Practice varies in different shops, depending upon the facilities for doing various classes of work, and, therefore, what would be considered the best plan in one shop would not work out in another. All the bolt holes in these sheets in some shops would be drilled in the erecting shop; the plates would be riveted to the smoke-box sheet with a few countersunk rivets, as shown, so as to hold these plates in place, until the cylinder bolt holes are drilled and reamed. In the latter case little layout work is necessary, except to locate the rivets so that they will surely clear the cylinder bolt holes.

The smoke-box sheet seam is invariably on the top center, as shown in Fig. 82. The rivets are spaced about 2¼ inches center, and the single welt strip is used. A good, tight job must be made of this welt strip, and this is true of all the other seams of the smoke-box. If the smoke-box is not tight air will leak in, and the soot and the unconsumed coal will take fire. This trouble has happended on many locomotives, and oftentimes caused serious annoyance to the running of trains. If the spacing of these rivets is not shown on the drawing, care should be taken in laying out the rivets so that the sheets will be drawn up tight. This illustration shows four holes which are necessary for attaching the smoke-stack and also circular opening of the smoke-stack.

The method of connecting the smoke-box sheet to the smoke-box front ring is illustrated in Fig. 83. The front end of the sheet is planned at an angle for calking, and the sheet is set back ⅛ inch for calking. The rivets are usually ⅞ inch diameter, and are frequently required to be countersunk on the outside at certain places, if not all the way round the boiler. The holes are marked off on the ring from the sheet and are drilled to suit.

Fig. 84 shows the construction which is used for connecting the first course to the front tube sheet and also the connections to the smoke-box sheet. *R* is a forged ring, 1 inch thick by 15 inches wide, which is used for making the connections for these three sheets. The ring is welded at the seam, and is turned off along the outside back edge for calking. Two rows of rivets are required, there being sixty-eight in each row. Begin the front one of these two rows on the top center line; as there are sixty-eight rivets there will be seventeen in each quarter. These will be stepped off with the dividers, making the spaces equal. The run of the outside of the sheet must be taken after the seam is welded; this must be checked up with the run for the first course. This must be done in order to be sure that the sheets will match up when the ring is put into place. The front tube sheet is riveted to the ring by 1-inch rivets. The drawing calls for eighty-five rivets in the cir-

cumference. Step off seventeen equal spaces, beginning on the top center line, and ending on the top center line. Divide each one of these spaces into five equal parts. A double row of rivets is also used for connecting the smoke-box sheet; fifty-four rivets are required in each one of these rows, and these rivets are laid off to suit.

The smoke-box extension is often made of lighter sheet than the smoke-box proper. The connection between these two sheets is made by an intermediate ring, shown in Fig. 86. These rings are welded, and are turned off to the inside diameter of these two courses. Forty-five rivets, 11-16 inch in diameter, are wanted in the back row and forty-nine rivets in the front row. In reference to this odd spacing of rivets it should be mentioned that in some shops it is customary to make the number of rivets in the circumference always divisible by four. This gives a certain number of rivets in each quarter, and thus assists the layer-out in laying out his work.

Fig. 87 shows an intermediate ring, which has an off-set forged along the lower part; this is extended to receive the bolts which pass through the cylinder flange. The ring is symmetrical throughout except for the spacing of the cylinder bolt holes. A plan view of this ring is shown in Fig. 88. The remainder of the rivet holes are equally spaced to suit the number of rivets called for on the boiler card.

The necessity for reinforcing the smoke-box has been mentioned, and a number of methods for doing this has been shown. Liners are also required to stiffen up the sheet in the water space where the furnace bearers are attached to the boiler liners. The studs which pass through the furnace bearer are tapped through the sheet into the liner. Reinforcement is often required for making the connections for blow-off cocks, whistle elbows, injector checks, etc.

Fig. 89 shows a ½-inch liner which is used for stiffening up the sheet for injector check. It is held by four ⅞-inch rivets, and six studs are tapped through the shell into the liner. The pilot and front bumper are stiffened up with a smoke-box brace, and this brace has a flat foot in connection with the bumper at one end and a round eye for connection with the boiler at the other. Fig. 90 shows the connection for the boiler; this eye is riveted to the boiler with four rivets as shown. In order to make a good, stiff job of this brace a liner is used on the inside of the sheet. The four rivet holes are laid off and punched into the shell. These are then scribed off on the liner and the holes are punched into the liner to suit. The eye of the brace is now heated and pounded up into place all around. The holes are then marked off and drilled to suit.

Oftentimes cylinder pockets are required on a boiler, and the drawings do not indicate it. In laying out the smoke-box or the extension this must be looked into in order to provide an opening for the pocket and holes for the rivet. In Fig. 91 is shown one of these cylinder pockets. The hole is circular, and the rivets are laid out in a circle on a flat sheet. When the boiler comes to the erecting shop, the cylinder pocket is chipped to a good fir all around, and the holes are scribed off on the casting and drilled to suit. The cleaning hole must also be looked up if this is not shown on the boiler card, as it will be placed near the front end of the smoke-box sheet.

In Fig. 92 is illustrated a cleaning hole. In the absence of any information care must be taken in laying this out, so that it will not interfere with the necessary parts that go with it. In the layout for the first and second course, usually waste sheet and guide-bearer sheet supports are required. These are usually made of T-iron or angle-iron. In Fig. 93 is shown a T-iron connection. This is bent to fit the boiler, and the holes are scribed off from the sheet and drilled into the T-iron. An angle-iron connection is represented in Fig. 94. The holes are marked off in a similar manner, and where the material is light the holes are punched. After the holes are punched the angle will spring and will not fit the boiler. It must be bent one way or another so as to fit up snug all around. The waste and guide-bearer sheets are trimmed short enough so as to give ¼ inch clearance all around, for ease and fitting up. This sheet is then bolted to the angle or T-iron by a series of bolts similar to that shown in Fig. 94.

CHAPTER V.

SMOKE-BOX FRONT DOOR, STACK, ETC.

In the present issue the smoke-box front door, stack and accessories will be treated. There is almost an endless variety of smoke-box front ends in use, and one can point out in so brief a space only those which are in common use, and which are accepted as being generally satisfactory.

One of these methods is shown in Fig. 95. This front end is made of pressed steel, and is formed in the hydraulic flange-press to the desired shape. It is then turned off on the edge as shown by the finish mark *f*. The door is very stiff, and when the surfaces are properly machined the joint remains good and tight all around. It has been during only the past few years that this door has been used to any great extent in this country, but it has been used abroad for a good many years. The door is held in place by a 1¼-inch T-head bolt in the center. The handle *H* is tapped to fit the bolt and acts as a nut. By unscrewing the handle the T-head bolt can be given a quarter turn, and the door can be swung open. In the present construction a hole is machined into the door and the number plate is riveted over. The hinges *H* are made of forged steel or hammered iron, and must be fitted in place.

A detail of these holes is shown in Fig. 96. The part extending over the door is made 3 inches wide, 5-16 inch thick on the end, and ⅝-inch thick at the hinge. The center line *CC* of the hinges must pass tangent to the door at *A*, in order to clear the door when it is swung open. This brings the hinge away from the smoke-box sheet a considerable distance, as shown in this figure. The amount of the overhang depends upon the size of the boiler and the available space for fastening the hinge; generally the overhang is greatest on the boilers which have the largest diameters.

The strap is forged approximately to drawing sizes, the door is then put in place and the hinge is heated to a red heat and pounded up against the door and the smoke-box in its proper position. The holes are laid off on the strap to the best advantage and drilled. They are then marked off on the door and the smoke-box sheet, and these are put in with either the ratchet or a portable drill.

Another form of front end is illustrated in Fig. 97. *F* is a flat sheet which is cut out of a steel plate on the rotary shear. It is then turned off on the outside edge and faced to fit the ring. The hole *H* is cut into the plate, of the required diameter, and the plate is faced off on the outer edge for the door. Strike a circle on this plate 53 inches in diameter. Draw two center lines *AA* and *CC* at right angles to each other. The drawing calls for twenty-four ⅞-inch bolts; this gives six bolts to each quarter. As nothing is stated to the contrary, we will begin the bolts on the quarter lines and step off six equal spaces in each quarter. In a similar manner strike a circle 38 inches in diameter and lay off twelve equal spaces for the clamps. The hinge is made up of a strap and block. The strap is forged to fit the door and is riveted as shown in Fig. 98. An angle-iron is sometimes used for this purpose. As few boiler shops, however, have angle-bending rolls for bending these angles, the solid ring is preferred. In addition to this the solid ring makes a stiff, strong front end, and this is desirable, as a smoke-box brace is usually attached near this ring. It is faced on the outside diameter and on the front, as shown by the finish marks *f*, Fig. 98.

The smoke-box is 54 inches in diameter, and the ring is 3¼ by 3 inches in the rough, or 3⅛ by 2⅞ inches finished. The smoke-box sheet is kept back ¼ inch from the edge so as to give an edge for calking. Fifteen-sixteenth-inch holes are drilled through the ring for ⅞-inch rough bolts. The illustration shows button-head rivets inside and outside. Oftentimes these heads are specified countersunk on the outside, and in

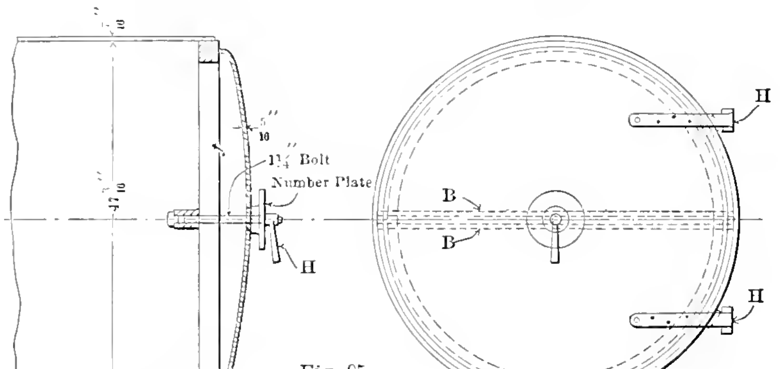


Fig. 95

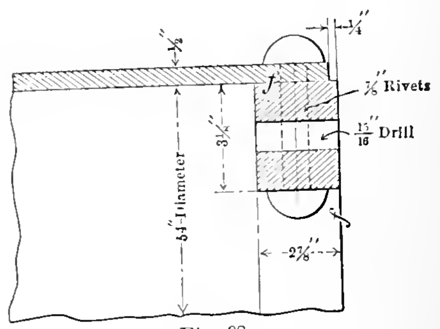


Fig. 98

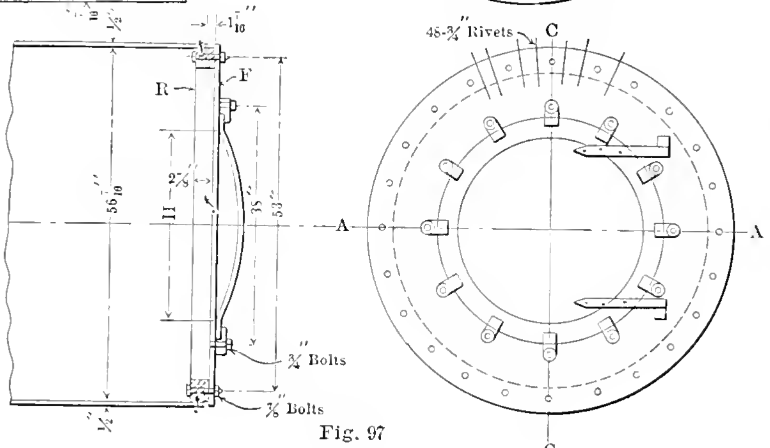


Fig. 97

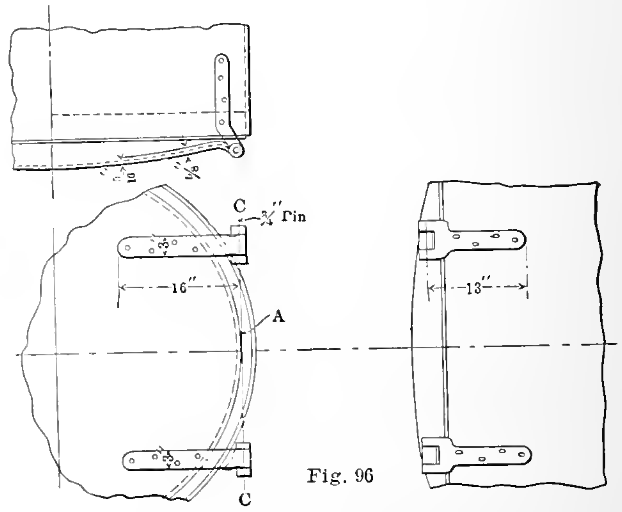


Fig. 96

to it; the block is turned off so that it will pass through the door in the form of a stud, and is held in place by a nut on the inside.

The ring *R* is made of forged steel and is faced off on the outer edge and outside diameter only. Twenty-four holes are laid off to suit the smoke-box front, and forty-eight ¾-inch rivets are required for the fire-box sheet. These will be laid off between the center lines as shown, 1 7-16 inches from the outer edge. The drawing calls for ⅞-inch rough bolts, and, therefore, the holes will have to be drilled 1-16-inch large. Where there are a number of boilers to be built with the same size front, a sheet-iron gauge would be made, and with this gauge the holes would be laid out, both on the smoke-box front and on the smoke-box front ring. The alinement of the holes is thus more certain, and the work of laying out is simplified and made much stouter, also affording the advantage of getting out a number of fronts complete without fitting the same to each boiler.

The front smoke-box ring is usually made of forged steel, any case these rivets should be looked up by the lay-out man, and the smoke-box sheet and ring should be marked to suit.

Fig. 99 shows a cast-iron front. The casting is set upon the boring mill and faced off on the top and bottom as shown at *f*. The holes for the ¾-inch bolts are twenty-four in number, and will be laid off either from a metal gauge, or as shown in Fig. 97. The lugs for hinges are cast on the front, and the door has an extension which fits in between these, and also cast on the door. The door must be faced off so as to form a tight joint. The clamps *C* are drawn up by ⅝-inch rough square-head bolts which fit in pockets, cast in front so as to keep the bolts from turning. A handle for opening and closing the door, and a number plate for the locomotive are usually a part of the front door.

In Fig. 100 is shown a general view of a smoke-box extension, together with intermediate rings, extension liner, etc. The cleaning hole is required on the left-hand side, 10 inches up from the center. A cinder pocket is located on the bottom center line, 10 inches back from the front.

The smoke-box sheet is ½-inch thick, and the extension is 5-16-inch thick. The smoke-box liner is ¾-inch thick, and the extreme liner ½-inch thick. A layout for this extension is shown in Fig. 101. This sheet will be planed on all four sides. It will be square on the back edge and on each edge of the seam, and will be beveled off for calking on the front edge. The sheet will be 17¾ inches wide when finished. Draw the front line of the sheet, allowing about ⅛ inch for planing. Measure off 17¾ inches at each end and draw the back line of the sheet; bisect this distance at each end of the sheet and draw the sheet center line *CC*. This seam butts together on top and has a welt strip on the inside only.

The print calls for the smoke-box extension to be 5 feet 10 inches outside diameter. The sheet being 5-16-inch thick, we will have 69 11-16 inches for the neutral diameter. We get the length of the sheet by looking up the circumference corresponding with 69 11-16 inches. By referring to the table of circumferences of circles we have,

Circumference of 69½ inches	=	218.341 inches.
Circumference of 3-16 inch	=	.589 inch
Circumference of 69 11-16 inches	=	218.930 inches.

We, therefore, measure off this distance along the center line *CC*, allowing ⅛ inch for planing on the edge. The other edge will be sheared off, and both ends will be planed off to the line. We now bisect the distance and draw the bottom center line *DD*; bisect the left half and draw the left side center line *EE*; bisect the right side and draw the right side center line *FF*. The blueprint calls for seventy-two 11-16-inch diameter rivets for the front ring. This gives eighteen to each quarter, and also calls for the rivets spaced off center. We therefore set the dividers by trial, and step off eighteen equal spaces in one quarter. Lay off each rivet midway between these points. In a similar manner lay off eighteen rivets in the other three

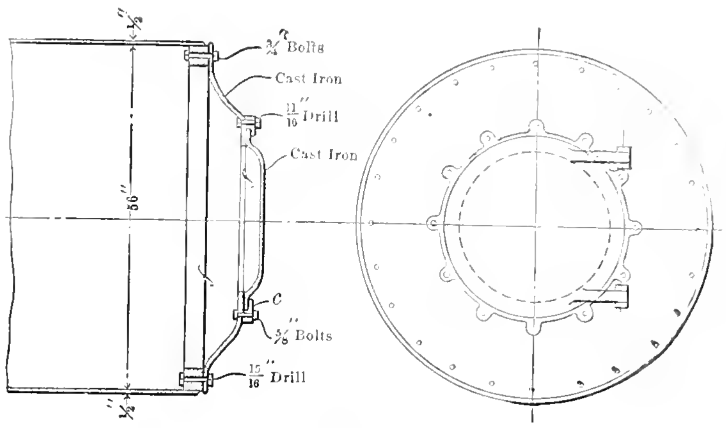


Fig. 99

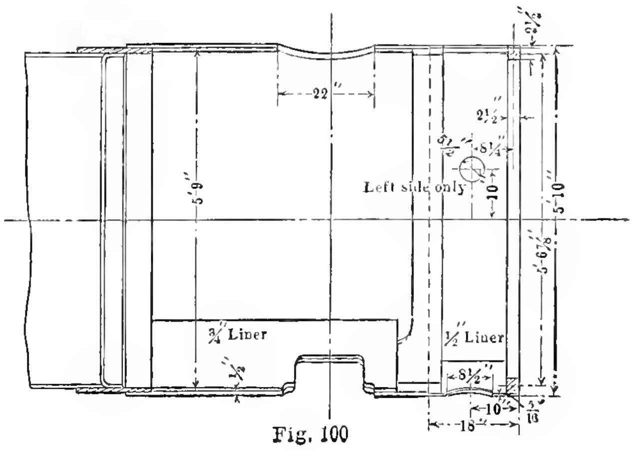


Fig. 100

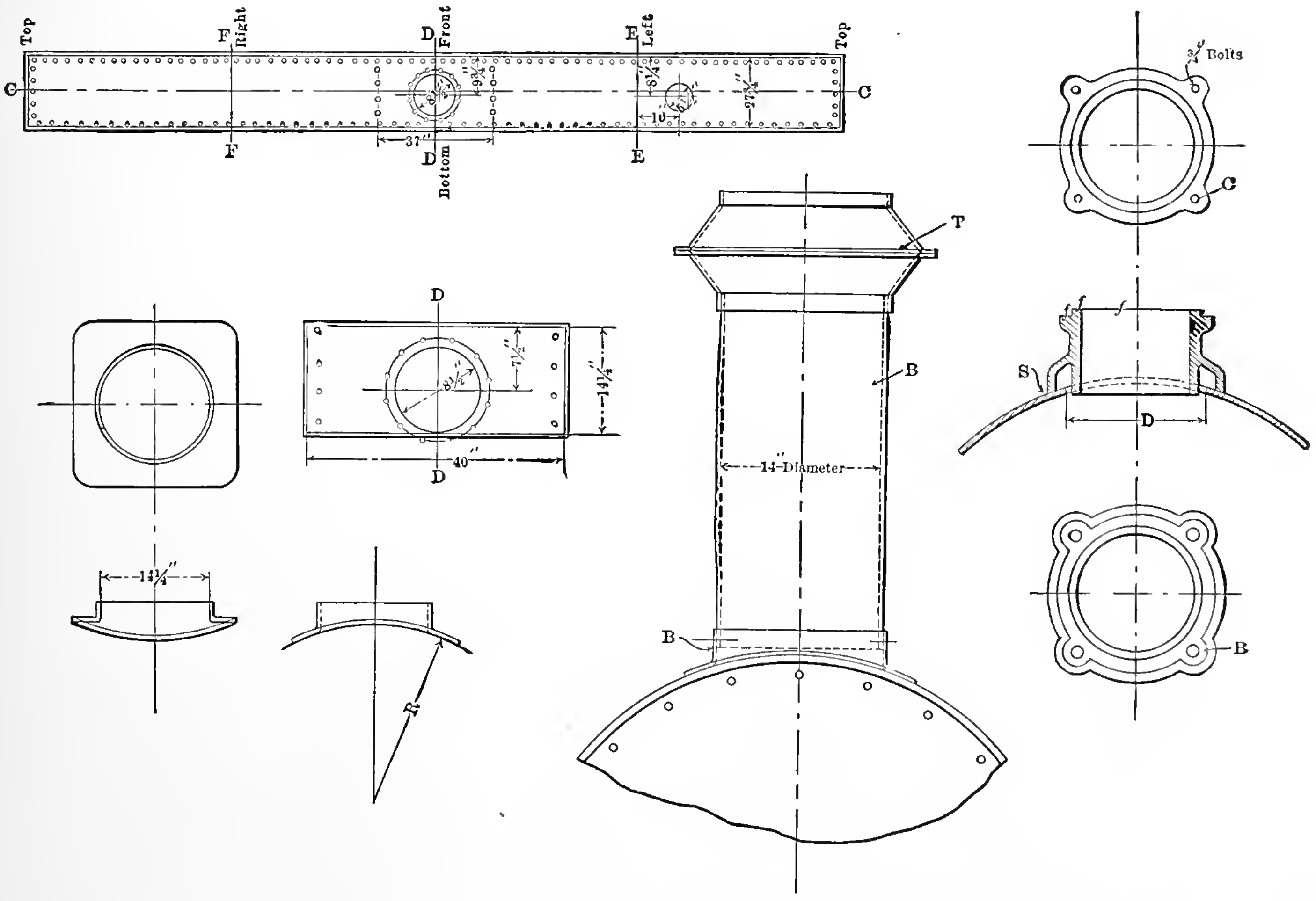


FIG. 108. FIG. 101 (TOP). FIG. 102 (CENTER). FIG. 104. FIG. 103.

quarters. The blueprint calls for forty-nine 11-16-inch diameter rivets for the intermediate ring. These rivets are also to be spaced off center on top. Set the dividers as near the pitch as possible, and step off these forty-nine spaces. As a check on the accuracy, the bottom space should come on the line *DD*, and the rivets should come in a similar position along the right and left side center lines. In laying out the holes for the cinder pocket it will be found that these will interfere with the bottom center line, and in its place will be used the holes for the cinder pocket. These holes are laid out 9¾ inches back from the front line on the bottom center line. Step off the twelve equal spaces, beginning to space midway between the center line. The hole required is 8½ inches in diameter. Measure up the distance 10 inches from the left side center, and 8¼ inches back from the front rivet center line, and lay out a hole 5½ inches in diameter. Draw a rivet center line 1¾ inches from the end line, and lay off five rivets equally spaced between the center lines. In a similar manner lay off five rivets on the other end of the sheet. Draw two rivet center lines 37 inches apart, and lay off four rivets on each line, equally spaced. These will be marked for 11-16-inch rivets.

Lay out a liner, Fig. 102, on ½-inch plate. Mark the length 40 inches and the width 14¼ inches. This liner must fit in between the intermediate ring and the smoke-box front ring. Draw a center line *DD*; measure back a distance 7½ inches from the front line and lay out a circle 8½ inches in diameter. This circle will be cut out from the flat sheet. The holes will be marked from the shell and punched to suit. The sheet will have to be planed along the front and back line, but will not need to be planed along the end line.

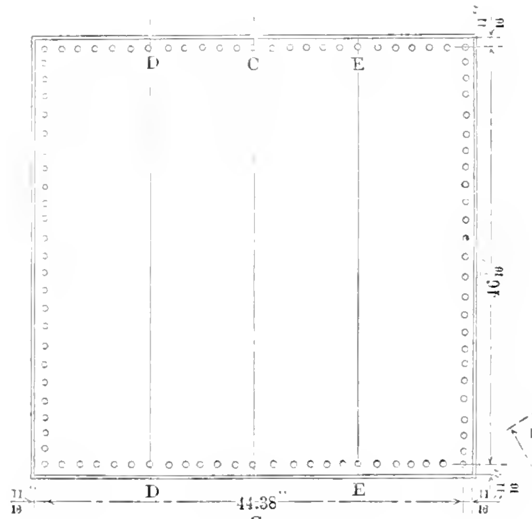


Fig. 105

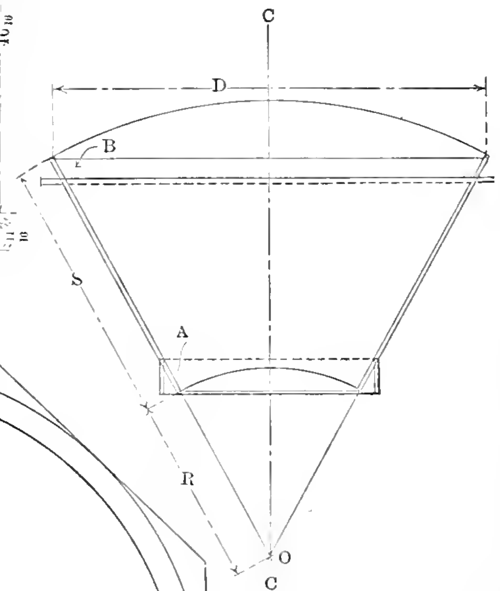


Fig. 106

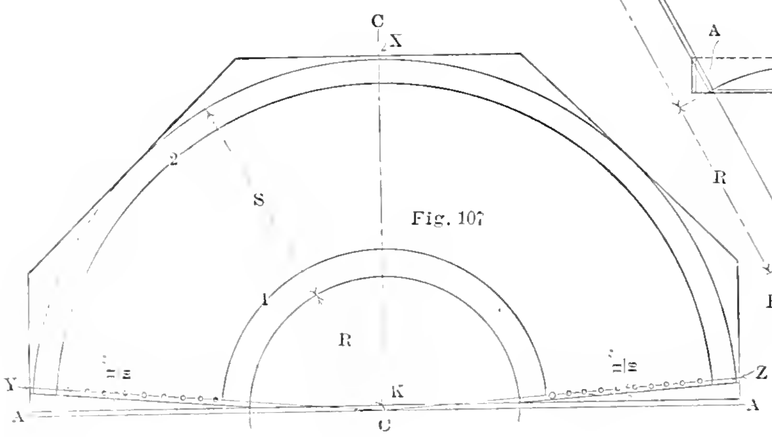


Fig. 107

We now come to the stack of the locomotive boiler. Many of these on modern well-equipped roads are simple indeed, consisting frequently of a short cast-iron cylinder, bolted either directly to the sheet of the smoke-box or attached to a cast-iron base, as shown in Fig. 103.

Many stacks, however, are built up of steel plates with spark catchers, etc. These are often complicated and require considerable time and patience on the part of the lay-out gang.

Little work is required for laying out a cast-iron stack, especially when it is of the type that is bolted directly to the sheet of the smoke-box. The laying-out work consists of locating the holes for attaching the stack, and seeing that these fit the boiler. A cast-iron smoke-box base is shown in Fig. 103. *D* is the hole in the smoke-box sheet. This must be made larger than the base by ¼ to ½ inch all around, in order that the base may clear nicely on the sides when the sheet is bent. The casting has an allowance for chipping at *S*. It is placed on the boiler and properly leveled. It is then marked off and finally chipped so as to fit the boiler "nice and neat" all around. Four bolts, *B*, are used for attaching the base to the smoke-box. The top portion is machined off as shown, and the stack is bolted to the base by four bolts, *C*, each ¾ inch diameter.

A sheet-metal stack is shown in Fig. 104. The body *B* is bent up in the rolls and riveted along the vertical seam by a single row of ⅜-inch rivets. The top of the stack *T* would vary in size, depending upon the fuel, location, etc., but in general construction would resemble the illustration. The base *B* is flanged out of the single sheet, and is riveted directly to the smoke-box. The body of the smoke-box is 14 inches in diameter inside, and the sheet is ⅛-inch thick; the

neutral diameter, therefore, is 14⅛ inches. By looking up the table of circumferences, we find

14 inches circumference = 43.9824 inches
⅛ inch circumference = .3927 inch

14⅛ inches circumference = 44.3751 inches

Referring to Fig. 105, the distance between the rivet lines would be 44.38 inch. The width of the seam is 11-16 inch on each side. This sheet will not need to be planed, and should come from the squaring shears with very square edges. If the edges come bad, however, allow only sufficient metal for trimming; if the edges are reasonably straight, work clear to the edge of the sheet, and do all the trimming on the two sides. Draw the center line *CC* and the quarter center lines *DD* and *EE*. The distance between the top and bottom center lines is 46 7-16 inches. Allow 7-16 inch from the width of the seam on the top and the bottom. Draw the top and bottom center lines. Step off six equal spaces on each quarter for the circumferential rivets. Step off twenty-four equal spaces for the vertical rivets. This completes the work on this sheet. The sheet must, however, be scarfed where it enters the base and top, and, therefore, these two corner holes should not be punched until after the sheet has been scarfed out. Where standard stacks can be used, this laying out is all done by metal gauges.

In order to lay out the cone portion of the top of this stack, sketch out a cross-section of this cone full size, Fig. 106. Draw the cone center lines, which continued will give the center *O* of the cone. Project the flange at *A* upon the neutral line, and thus obtain the length of the radius *R*. Also project the flange at *B* upon the neutral line and thus obtain the length *S* of the element of the cone. From the extremity of the projected portion at *B*, lay out the neutral diameter *D* of the cone at this point. With these figures we can proceed to lay out this sheet, Fig. 107. Select the proper sheet for the purpose, and draw the center lines *CC* and *AA*. Strike a circle with radius *R* in Fig. 106. Strike an outer circle with a radius equal to *R* plus *S*, Fig. 106. From the table of circumferences look up the circumference corresponding with *D*. Beginning at *X* with the wheel, run around the outer circle a distance equal to one-half the circumference which has just been found, and thus obtain the point *Y*. In a similar manner, run around the other side and obtain the point *Z*. Now begin at *Y* and run around the circle and see that this checks up with the total distance. Draw *YK* and *ZK* to the center of the circle. These are the rivet center lines.

Lay off the end line of the sheet 11-16 inch from the rivet center line. Strike two circles *1* and *2* for the bending line of the sheet. Divide this distance between these lines into nine equal spaces and locate a rivet midway between the spaces thus laid out. Several other rivets will be required, but these will not be put into the sheet until after it has been flanged. Both of the top sheets will be laid out in this manner, as also many of the spark catchers, deflecting sheets, etc. The base, Fig. 108, is flanged out of a single sheet, and the holes are marked off on it from the stack, and from the smoke-box, and these holes are then punched to suit.

CHAPTER VI

DEFLECTING PLATES.

Various methods are used for deflecting the gases in the smoke-box in order to get a more uniform distribution of heat throughout the tubes. A gas in motion follows pretty much the same law as a solid does when it is in motion—it tends to move in a straight line, and if it is desired to bend it out of this line, some outside influence must be brought to bear upon it.

Without any deflecting plates in a locomotive boiler, a heavy flow of gases will take place in the upper tubes, while there will be scarcely any flow in the lower tubes. This unequal flow causes unequal heating, and consequently unequal expansion of the tubes. This gradually loosens up the setting of the tubes, and will start the joints leaking. All this is bad and, in addition to this, the operation is more economical when the gases flow more uniformly through the tubes. For this reason a deflection plate is placed in the smoke-box, in order to dampen or check the draft in the upper tubes, and thereby increase the draft in the lower tubes, as shown in Fig. 109.

The air passes up through the grate in order to produce combustion, and the hot gases are bent over and pass through the tubes. The deflecting plate *D* bends the flow of the gases of the upper tubes downward, and then the strong draft produced by the exhaust drives these gases out of the stack, together with a lot of sparks, soot, etc. It is the sparks, soot and unconsumed coal which is the source of great annoyance in nearly every locality. And the extent of this annoyance often determines the arrangement of the smoke-box, screens, spark arresters, etc. Stringent laws are enacted in some localities specifying that some arrangement must be used in order to arrest sparks, soot, etc. The deflecting plate, spark arresters and screens of the smoke-box, are often looked upon as being unimportant, but there is scarcely anything about the locomotive that has been the source of so much litigation between the railroad and the locomotive builder, and between the public and the railroads, and therefore great care should be exercised in the design and construction of these parts, whether it is a locomotive works building an engine for an outside party, or whether it be the railroad's home shops.

A cross section of a smoke-box as used extensively is illustrated in Fig. 110. *D* is the deflecting plate, which is fastened permanently to the boiler. *S* is a slide, *F* is the opening for the exhaust pipe, *A* and *B* are sheets of metal or perforated plates having meshes or openings varying according to the fuel, size of the boiler and locality. *C* is an angle-iron which is bolted to the tube sheet ring. *E* is a piece of bar iron which supports the netting; it passes across the boiler and is bolted to the side of the boiler. The door *B* is hinged at *H*, and drops down in front, so that persons can readily get to this part of the smoke-box. Nearly all these sheets and netting run at an angle, and are therefore quite irregular in shape. Just what shape any particular sheet will have is difficult to tell, even by the most experienced men on this class of work, and the exact shape can be obtained only by a careful layout for the required conditions. In order to facilitate the work

of laying out these sheets and fitting them into place, they are made in two pieces, with the seam in the center. Each piece is fitted separately into place, and then the sheets are matched up along the center line.

In Fig. 111, *SS* are slots for adjusting the slide. Make a full-size layout of that part of the smoke-box which contains this sheet, laying out only those lines which would be crossed by this sheet; also make a front view of the end. These views can overlap each other for economy of space, so long as the layout remains clear.

Strike the circles corresponding with all parts of the smoke-box, intermediate ring, etc., which would be crossed by this sheet. Now lay all points along the neutral line of the sheet, and mark off the spaces 1, 2, 3, etc., to points where dimensions are to be obtained, and project the same over to the other view, and then measure off the width of the sheet from each one of these points to the center line *GG*, as shown at *A*, *B*, *C*, etc. These dimensions can now be laid off on the flat sheet. If the curved portion where the sheet fits along the boiler is long, several intermediate points should be selected. These would then be projected to the other view, and the width of the sheet at these points should be measured off. It will be noted that this sheet is bent at an angle of about 60 degrees, about 4 inches from the top edge. In ordering these sheets, be sure to specify the sheet so that the bend will cross the sheet at right angles to the length, as it is rolled. If this sheet is bent lengthwise of the rolled sheet, it is very apt to break.

Fig. 112 shows one of these sheets as it would appear when it is laid out on a flat surface. This sheet fits around the shell of the smoke-box without any interference of lines and rings, and therefore the outer edge will be a smooth curved line. A 2 by 2-inch angle is bent to fit the boiler and the deflecting plate, and is attached to the deflecting plate by a series of rivets spaced 4 inches center to center. An angle is often used at *A* along the top edge, for holding the sheet in place. A hole *H*, 11-16-inch in diameter, is laid off for the slide; also a series of holes is laid off, about ⅝ inch from the center line, for the seam rivets. All rivets covered by the slide in the several positions must have countersunk heads, which must be flush with the surface of the sheet.

In laying out the slide, care must be taken to have enough clearance on the side of the slide to admit of adjusting it to its fullest extent without interference on the side of the boiler. Also, this cut-out in the sheet should be not more than required, as a considerable gap is necessary in some cases in order to get the desired adjustment. This gap in its worst position allows the gases to rush past its side, instead of deflecting them.

Fig. 113 shows the slide in its top and bottom positions. We measure off the distance A_1, B_1, etc., from the center line to its outer edge in its upper position. In a similar way from the same points on the slide we measure off these distances on the bottom position. Lay out on the front sheet the least distance which has been obtained in these positions from the lines corresponding with *A*, *B*, *C*, etc. Then draw a curve through these lines and trim off the sheet to these lines, allowing about ½-inch projection beyond the center line for matching up. Usually the two halves of these sheets are symmetrical, and one lay out is all that is necessary. If there are any projections, heating pipes, etc., which would make one side different from the other, the sheet must be laid out for each side separately. Where the cut-outs are numerous and complicated, much time is saved by taking the sheet to the smoke-box, placing it at the proper angle and position, and then marking out with a scriber the parts that are to be cut out. The metal is then pared away to these preliminary lines, and the sheet is then taken back and put in position, and again carefully scribed off from the side of the boiler and projections, so that when this metal is cut away the sheet will slip back into place and fit snugly all around.

The door *D*, Fig. 110, is usually made of wrought iron ⅝ by 3 inches, and is bent to fit the boiler along the outer edge and is welded together at the corners—see Fig. 114. To get the shape of this in a flat piece, we lay off points, 1, 2, 3, etc., along the neutral line, and get the distances *A*, *B*, *C*, etc. On a flat sheet, Fig. 115, draw a center line *CC* and a base line *DD*. Lay off on *CC* O_2, 1_2, 2_2, 3_2, etc., and draw lines parallel

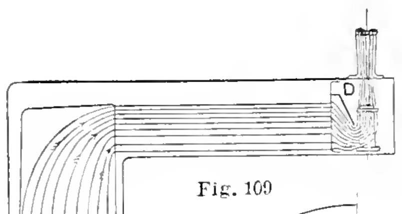


Fig. 109

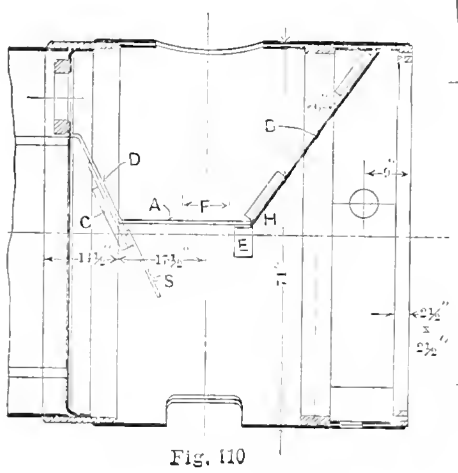


Fig. 110

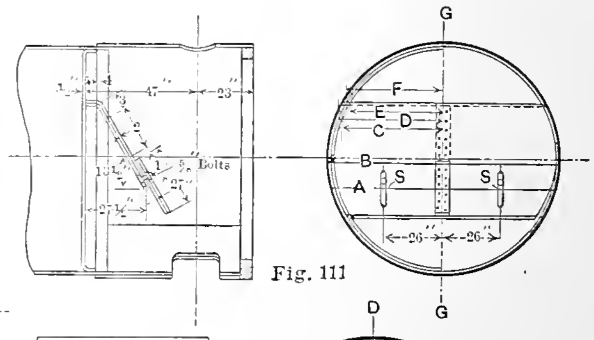


Fig. 111

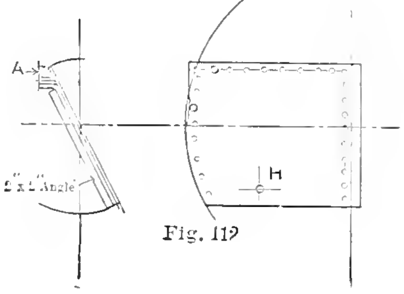


Fig. 112

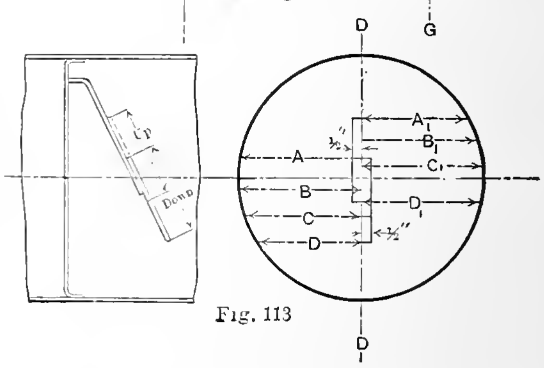


Fig. 113

to *DD*. On each side of the center line *CC* lay off distances A_2, B_2, C_2, etc., corresponding with dimensions obtained from Fig. 114. Draw a smooth curve through these points.

The door is then forged from ⅝ by 3-inch stock to conform with these lines, and a piece is welded in to form the bottom. When netting is used, a frame is placed on the netting and the netting cut to suit. Holes are placed in the frame for 5-16 or ⅜-inch bolts, and washers are used between the head and the netting. The frame is hinged on the bottom, and is held in place on the top by a key and strap bolt—see Fig. 116. The bolt is 1⅛ inches in diameter and has a split key ⅜ by 1¼ inches. The strap portion is ⅝ by 3 inches, and is riveted to the sheet by two ⅝-inch rivets. Care must be taken in settling on the position of this door, in order that it will clear the side and the ring as it sweeps through the radius *R* from the center of the hinges. Never skin too close on the clearance allowed, as there is always bound to be more or less variation in the fitting up of these parts, and then you will have trouble with the door interfering with other portions of the boiler. Generally, if the end of the door clears the ring at *K* by 1¼ or 1½ inches, the rest of the door will clear also. But this is not always true, especially when the slope of the door is made very steep. The inside circle of the ring should be laid out on the cross section, and several points should be projected on the outer edge of the door in its top position. Now rotate the door and project these points to the cross section. You can immediately see whether the door clears or fouls.

One of the meanest things to fit up in connection with the netting or perforated plate, is the flat plate *A*, Fig. 110. This illustration does not show the steam pipes which pass down along each side. There are also frequently special pipes, angles, etc., which this sheet must fit around, and therefore the fitting in of these sheets often become a tedious and troublesome job. Ordinarily the laying out of these parts is made easy by the use of stiff paper. Several boards are leveled up in the position of this sheet, and the paper is cut so as to fit around the parts nicely. The ease with which the paper can be bent in around corners enables one to cut the paper out in a short time and make a very nice job. This is then transferred to the netting or perforated plate, and the latter marked off and cut to suit.

Oftentimes it is necessary to cut a large hole out of the plate or netting, and then fit an extra small piece in around the parts, and bolt this to the main part of the screen. Also this is often rendered necessary in order to make it easy to get these sheets in and out of place. A hole must be cut into this sheet in the center so as to fit around the exhaust pipes. The screen is usually bent up and bolted to the deflecting plate *D*. The usual arrangement of the steam pipes is shown in Fig. 117. The part of the sheet extending behind the steam pipe at *K* and *K*, would be fitted in by the small piece which has just been referred to.

Sometimes a basket *ABC* is arranged out of netting; *AC*, being a part of the cone, would be laid out by continuing these two lines to their intersection, and then by measuring off the inner radius to the point *R* and the outer radius to the point *P*. We then strike these two circles, look up the circumference corresponding with *D* and then measure off this distance along the outer circle. Draw two radial lines from these points to the center, as shown in Fig. 118.

Now lay out this cone on the cross section and determine the distance *K* on the drop back from the top line. Lay off *K*, Fig. 118, on the right and left side center lines, and with the straight edge draw a nice, smooth, curved line as shown. To this sheet must be added a sufficient amount for flanging and attaching the basket to the boiler. We now bend the basket in shape and bolt the ends together. Raise this in position in the smoke-box, and with the scriber mark off the depth of the flange down from the shell of the boiler, running all the way around the sheet. We now bend the flange back, and then place the basket in position and pound the flange up nice and neat all around. The bottom of the basket would be flanged up on the inside and bolted fast, and the bottom would be cut out to fit the exhaust nozzle, or whatever the drawing calls for.

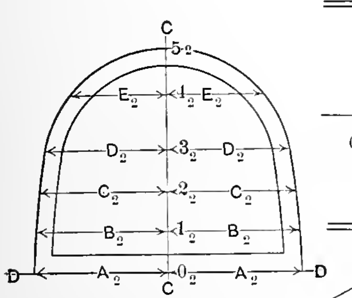


Fig. 115

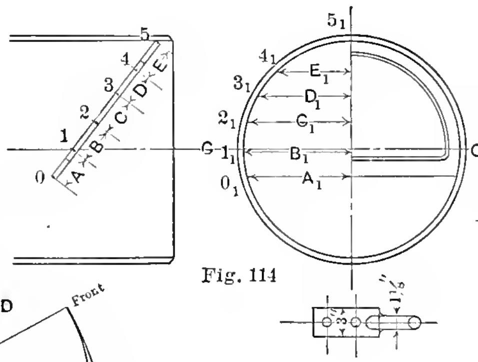


Fig. 114

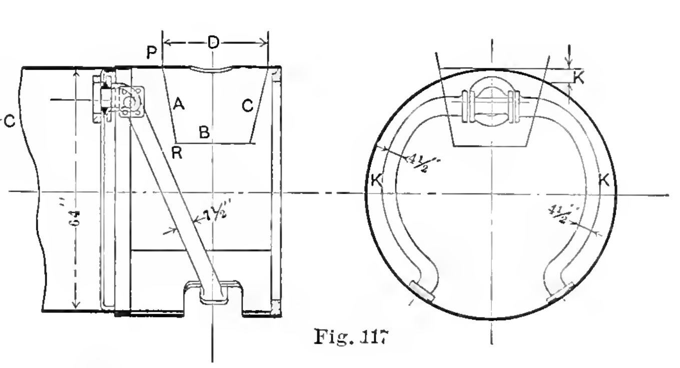


Fig. 117

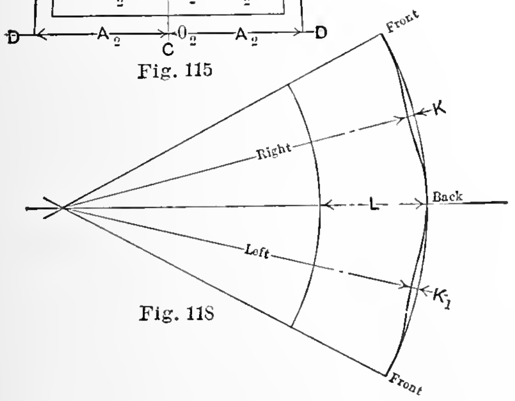


Fig. 118

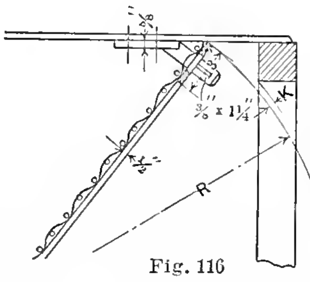


Fig. 116

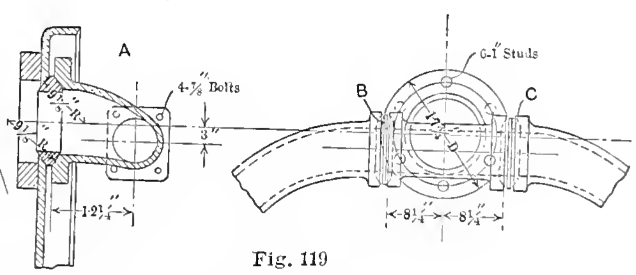


Fig. 119

A common construction of steam pipe is shown in Fig. 119. This shows a flange connection to the T. There will always be some variation in the machining of parts and fitting up, and therefore the ball joint arrangement is used, *A*, *B*, and *C*. Part *A* is shown in section: both the sheet and the T are reamed with a ball reamer to 9½ inches radius. The drop of the T, which is shown as 3 inches, may vary ½ inch or so one way or the other, and the steam connections will still remain perfect.

In fitting up the deflecting plates, screens, etc., some allowance must be made for this variation. A sheet which will be just right for one boiler will not fit in exactly in another, although the drawings for the two may be exactly the same. Also, there will be some variation in the pipes, due to expansion, which will also require some clearance.

CHAPTER VII.

LAGGING.

This section deals with the lagging of the locomotive boiler. There are a number of methods used for lagging boilers, each of which has its own peculiar advantage. In some cases this means an advantage in ease of putting on the lagging, which is, of course, an advantage to the builder. In other cases the lagging is more expensive, and of course serves its purpose as a covering to more excellent advantage.

On small locomotives, for plantation and light locomotive work, wood is often used for lagging. The pieces are sawed in strips about 3 inches wide, and in length and thickness to fit courses. These are held in place by hoop irons, which are wrapped around the boiler, nails being driven through the hoop irons into the wooden strips, thus securing the lagging. After the boiler is thus covered it is surrounded with a sheet iron covering. This is an inexpensive lagging, and is used a great deal.

Various compositions are used also, in the form of sectional lagging. Some of these are good enough for medium size boilers. On large locomotive boilers, however, for heavy freight and passenger service, magnesia sectional lagging is largely used.

Fig. 120 shows an outline of a locomotive boiler which is to be covered with sectional lagging. . . . A drawing or sketch of the boiler which we intend to lag is sent to the lagging manufacturer. Here, a full size layout is made, showing thickness of plates, slant, diameter of sheets, etc. The various courses are then gotten out so that they can readily be put together in the erecting shop. Each piece is about 5 inches wide, and in length varies from 2½ to 3 inches, depending upon the length of courses, position of dome, throat, sheet, etc. The number of pieces required for any given course, as, for instance, the first course in Fig. 120, would be obtained as follows: The boiler is 64¼ inches outside diameter; lagging to be 1½ inches thick. This gives 65¾ inches to the neutral diameter of the lagging, or 206.56 inches circumference. With sections 4½ inches wide we would have forty-six pieces. A little more than the exact amount is furnished in order that the last piece may be sawed and fitted. The various sections are held to each other, and the whole thing is bound together by the use of corrugated pieces of steel, as shown in Fig. 121.

The lagging for the dome is shown in Fig. 122. The sections are tacked to each other and built all around the body of the dome. The whole thing is then inclosed by a dome casing, *C*, which is made of thin sheet iron. The top of the dome is frequently plastered over by a mixture of the same material which makes up the sections. The back head of the boiler in many cases is not covered with lagging, the lagging proper extending to the edge of the outside sheet. An angle-iron *A*, Fig. 123, is bent to fit the boiler, and is held in position by screws and clamps. The lagging is fitted underneath the leg of this angle. This holds it securely in place, and also protects the lagging from ill usage in the cab.

This same style of angle-iron is also used along the cab board, down along the throat sheet, and across the bottom of the throat sheet, in order to hold the lagging firmly in place at these limiting places. When the back head is specified to be covered with lagging, care must be taken to bind the sections firmly together and tie them securely to the side of the boiler. This is usually done by means of wire and clips to hold the ends together. In putting on the fittings, such as whistle, elbows, blow-off cocks, cleaning plugs, etc., care must be taken to have these fittings made longer, so that they may pass through the lagging. After all the lagging has been put

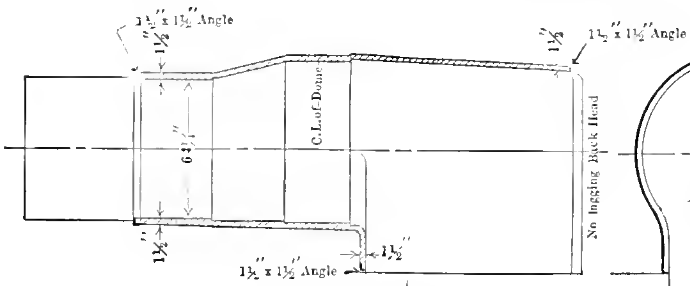


Fig. 120

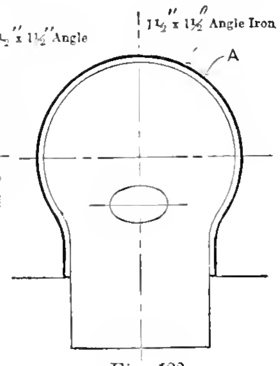


Fig. 123

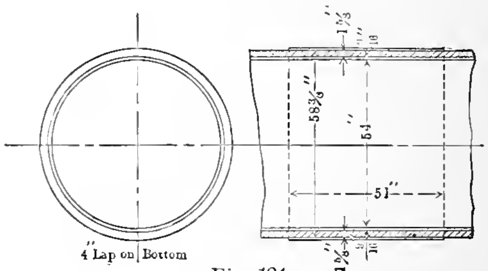


Fig. 124

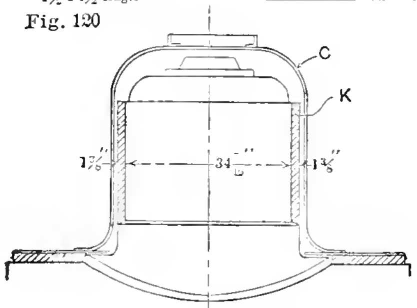


Fig. 122

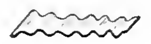


Fig. 121

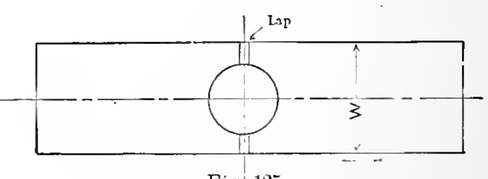


Fig. 127

on the boiler, whether this lagging be wood, magnesia sectional, or plastered on, the entire surface must be covered with sheet iron, usually Russian iron sheets are used for this purpose.

Illustration Fig. 124 shows a portion of the barrel of the boiler with the lagging and sheet-iron cover in position. The breadth of the sheet would be determined by the character and shape of the boiler. The length would be determined as follows: In the illustration the drawing calls for a boiler 54 inches inside diameter, and the shell is to be 9-16 inch. This would make the outside of the boiler 55⅛ inches in diameter. The lagging is to be 1⅝ inches. This would make the diameter over the lagging 58⅜ inches. In the table of circumferences we find that 58½ inches diameter, which is ⅛ inch more than is required, would give us 183¾ inches, to which we add 4-inch lap, which would give us 187¾ inches, or 15 feet 7¾ inches. This would be made up of several sheets riveted together, the lap being made in such a way that the outside sheets hang down over the top of the other sheets, thus shedding the water. This style of sheet is by far the easiest thing to make. The covering for the gusset sheet, dome course, back head, etc., are considerably more difficult.

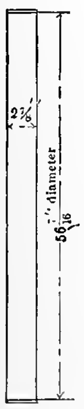


Fig. 126

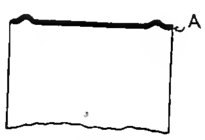


Fig. 127

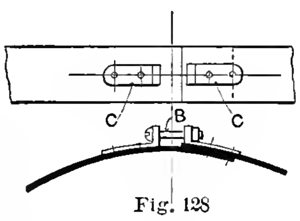


Fig. 128

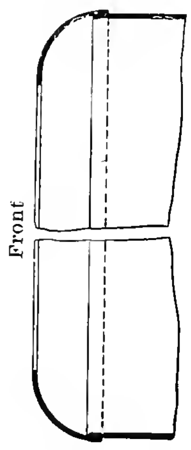


Fig. 129

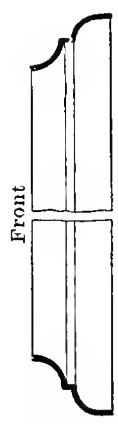


Fig. 130

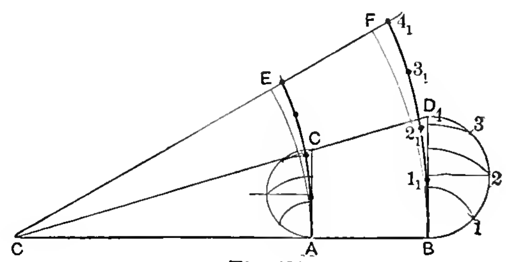


Fig. 131

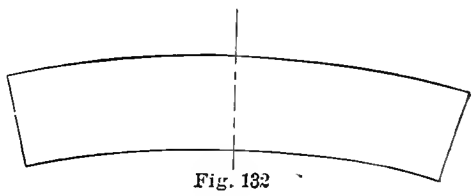


Fig. 132

The sheet for the dome course extends on in as near the body of the dome as possible, and the seam is lapped over on the top as shown in Fig. 125. The width of this sheet, *W*, would be made sufficient to cover the dome course, and give from 1 to 1½ inches between this sheet and the one that covers the next course. When the sheets are put in position, they are held in place by a circular band, Fig. 126, about 3 inches in width, and in length to extend all around the boiler and allow 4 or 5 inches lap. These bands are beaded on the ends, first for appearance, and, secondly, in order to make a neater fit between the band and the sheets which it holds in place.

A section of the beading is shown in Fig. 127. *A* is the portion that is bent down and rests on the sheet, thus closing up the air-space and making the covering very tight. The band is clamped together by means of bolt *B*, Fig. 128, and a pair of clips, *C* and *C*. The clips are riveted to the band by several quarter-inch rivets. The one clip is placed near the end of the band, and the other clip is placed from the end 5 or 6 inches, depending upon the amount of the lap. The exact location for the second clip is obtained by placing the band around the boiler and pulling it up tight in place. The holes are then marked off from the clips. The exact location is a matter of judgment on the part of the fitter and must be sufficient to take out the slack of the band when the bolt is pulled up tight, and still allow sufficient thread for adjusting in case of an additional stretch of the band or contraction in the different courses.

The lagging on the front end is held in position by the leg of the angle. This angle is bent around the boiler and is held at a number of places by bolts. In order to give a finish at the front, where this lagging ends, a flange sheet, Fig. 129, is used. This is bent to fit the radius of the smoke-box and should fit up nice and tight all around. The back portion reaches over the back sheet, and the whole thing is bound equally together by a set of clamps and bolts.

Another style of ring for finishing off the front end is illustrated in Fig. 130. In getting out these rings, and especially the latter, care must be taken that there are no button-head rivets where this sheet rests against the box. When there is a row of button-head rivets around the boiler where this ring would naturally come, the lagging must be brought a little further ahead, or stopped off a little further back, in order that this ring may rest against the boiler without interfering with the rivets. The lagging cover for the gusset sheet is to be laid out as shown in Fig. 131. Get the drawing for the boiler and make a sketch for the large and small neutral diameter, and also the distance of these diameters from each other. Now, to these figures add the thickness of the shell and the thickness of the lagging, and to this add ⅛ inch extra on account of the inability to fit up the lagging and the covering and some air space. These figures give us the size of the cone for slope-sheet covering.

We lay out these figures as shown in Fig. 131, and continue the slope line *C D* until it strikes the bottom line *A B* at the point *C*. This is the center of the cone. From this point strike two reference arcs *AE* and *BF*. Also draw semi-circles on *BD* and *AC*, and divide these into four equal parts. From *A* and *B* as centers, with the trams project these points on the diameter. From the point *B*, with a radius equal to the length of the arc *B-2*, strike a circle as shown. Now measure off the radial distance from the reference circle to the point *1*, and step off this distance from the reference circle and determine the point 1_1.

In a similar manner strike another arc and measure off the distance from the projected point *2* to the reference circle. Lay off this distance from the reference circle and determine the point 2_1. Continue this construction until the point 4_1 is located. In a similar manner we make the construction of the small end. We thus have four points each for the large and the small end. Draw a smooth line through these points and add about 2 inches for lap. This represents one-half of the sheet. The other half would be symmetrical to this.

Where a number of these sheets are being laid out for boilers for slightly different dimensions, a person can often judge about what curve to give these lines, and thus the whole sheet is laid out in this time. The number of pieces that one of these sheets would be divided into would be determined by the size of the stock on hand, and the general dimensions of the boiler. Sufficient allowance must be made on the separate sheets so that when riveted together they will make up one complete sheet of the size required.

Fig. 132 shows this complete lagging cover for the slope portion of the boiler. The dome covering is represented in Fig. 122. The straight portion of the cylinder is made of one plain rectangular sheet. The ends for seams are sheared square and true. The sheet is bent up and the seam is riveted up with a covering strip on the inside, and the counter rivets on the outside. This seam is made very neat, and when finished and painted it should be impossible to see the joint. The top portion is made from pieces which are hammered out by hand and fitted together. Each one of these sheets is riveted up with strips on the inside, and the whole thing is riveted to the cylindrical portion of the dome covering. In a similar way the flange portion is built up. The whole of this casing is made to fit down neatly over the outside cover of the dome course. Holes must be provided for whistle elbows, throttle valves, rod connections, etc., which might be required on the dome.

CHAPTER VIII.

BOILER MOUNTINGS.

The mountings for the locomotive boiler are numerous, and usually require considerable thought and good judgment on the part of the erector, in order that the whole thing may go together nicely. Too often the work of laying out these parts is not done thoroughly enough, and therefore there is a good deal of tearing down and tearing out necessary to fit things together.

In the list of these mountings is included such parts as furnace bearers, waste sheets, etc., which will be attached to the boiler proper when it comes to the erecting shop, but which are no part of the boiler itself. In laying out these mountings many unusual things turn up. In laying out the various courses, the exact length called for on the drawings cannot always be obtained, for a number of reasons. First, a sheet may be ordered a little too narrow; or, on the slope sheet, when the layout is made, we may not have quite enough metal for the full width of the seam. Thus there are many things which change conditions far from the ideal. These changes may never be noticeable, or may never change the working of the boiler or the fitting up of the different parts. The man in the erecting shop is rarely "on to" any of these things until he gets "up against it" in setting the boiler up in place. Any juggling of the stay-bolts is noticeable, on account of the shifting of the stud-bolts for furnace bearers.

Fig. 133 shows a boiler which has been lowered onto the cylinder, and which is ready to be marked off so that the cylinder flanges can be chipped to fit the smoke-box sheet. The erecting card gives the distance *B* from the center line of the cylinder to the throat sheet. This distance must be exactly right. The erecting card always gives *C*, from the top of the frame to the bottom of the mud ring, or to some finished surface on it. These figures must be checked up, together with the distance *A* from the center line of the cylinder to the front ring. If there is any discrepancy due to any one of the causes which have been mentioned, the matter should be taken up carefully, so that the discrepancy will be thrown in such a way as to least affect the mounting. Having once determined definitely what these figures are to be, the chipping line for the cylinder is laid off, and the outline of the furnace bearer marked out a sufficient height above the frame to allow the boiler to drop down when the cylinders are chipped out. Having thus carefully laid out the furnace bearers, break-hanger supports, etc., the boiler is removed, the cylinders are chipped down to the lines by means of straight edge, and the boiler is put into place and leveled. The dimensions are now all done over again, and if everything is all right, the boilers are laid off for the cylinder flange bolts. The method of putting in these holes varies in different shops. This has been referred to in a previous issue, and therefore it will not be necessary to go over that matter at this time. The thing to remember, however, is, be careful and get the height of the boiler correct, and also the exact position longitudinally; and also be careful and get the center line of the boiler in line with the center of the frames.

The furnace bearer is often made of steel plate, bent as illustrated in Fig. 134. *A* is a filling-in piece between the outside sheet of the boiler and the frame. The boiler should be lowered into place, and the thickness of the sheet would be made to suit the measurement taken at this point. This sheet must be fitted to the boiler by means of patch bolts. The furnace bearer *B* is machined off where it sets on the frame, and is allowed to project over the frame a sufficient distance to cover up the plant.

The exact length of the foot is to be marked off in position, and the plate is then planed down to this line. The bearer will not fit up snugly against the boiler until it is countersunk in the back a sufficient amount to clear the head of the staybolt, as shown in Fig. 135.

Put a daub of white lead or moist flour on each of the staybolt heads which would be covered by the furnace bearer on the frame in its proper position lengthwise of the boiler, and push it back against these heads. Tap the bearer sufficiently to mark an impression at each one of these stay-bolts. Some of these points will be marked all right and others will not touch. Give these low heads an extra daub of white lead and apply the furnace bearer again. The furnace bearer is now to be center punched and taken to the drill press.

With a flat-nose drill, as shown in Fig. 136, each one of these center punch marks is to be countersunk, as shown in Fig. 137. One can soon judge about the depth necessary, and when all holes have been countersunk, the furnace bearer is taken back and tried in place. This flat-nose drill is always sure to creep one way or the other, so that the bearer will not clear all the stay-bolt heads. By using white lead on the heads and trying the bearer in place, you can find out where the interference is. Sometimes by countersinking deeper the ones that interfere, the bearer can be brought up in place. When they are very much out, however, draw the center line over with a round-nose chisel, or tilt the bearer up at an angle, so that the center will run in the desired direction; also see that the angle of the drill is about the same angle as the stay-bolt heads.

The bearer will rarely fit up snugly against the side of the boiler until it is bent to the side sheet, either by bending it cold, or by heating it and pounding it back in place. The clamp *D,* Fig. 134, is machined along the side and on the bottom, where it rests against the frame. The distance *E*, from the top of the frame to the bottom of the finished surface, is not always a definite figure, even on locomotives which are built to the exact design. The forging may come full at this point, or it may not, and when the frames are slotted this surface is merely trued up, irrespective of dimensions. The clamp, therefore, should be laid out at *E* so that it can be marked and planed to fit. The holes for attaching the furnace bearer and clamp are laid off on the diagonals between the stay-bolts, and are usually drilled a little large, so that there will be no interference with the studs.

Steel castings are also used for furnace bearers; see Fig. 138. These are usually harder to fit up than the forged steel bearers, as they are heavier and harder to handle. The casting is usually made with chipping strips. If the steel casting is not badly warped, these strips can be chipped off on the high spots until a reasonably good contact is attained all around. The arrangement of the clamp in this illustration is such that it is not bolted to the boiler itself. The distance, *T* however, must be made to match, as the width of the boiler will be constant, though the fire-box will vary more or less.

Often the furnace bearer takes the form of that shown in Fig. 139. *S* is a steel casting which is attached to the side of the fire-box by means of studs. The drawing usually shows the location of these holes, which should be spaced to avoid interference with the stay-bolts. The casting is chipped to the boiler in a similar manner to that shown in Fig. 138, and countersunk to clear the heads of the stay-bolts. Sometimes these castings extend on down, and take a bearing on the mud ring. A pad is arranged on this ring, and is machined, as also is the lip on the steel casting.

This takes the weight off the studs, and makes the work of lining up the casting much easier. *P* is a forged steel pin, which is forced into the casting and riveted over. *L* is the link, which takes the weight of the boiler, and also allows the boiler to expand and contract. *W* is the washer next to the link, and *C* is a split cotter, to keep the whole thing in place. The fire-box must be girded sidewise by a suitable cross-tie, which is machined out to suit the frame.

Most fire doors are made of cast iron, with ¼ to ⅜ inch chipping strip all around the edge, Fig. 140. The casting is raised in position, placed against the back head and leveled. The location of the holes *H* is then settled, in order to clear the stay-bolts. These holes are then drilled for ⅞ or 1-inch bolts, as the case may be. The casting is then raised again in position, and the holes *H* are scribed off. These holes are drilled and tapped, and the studs are screwed into place. The high parts of the chipping strip and the strip are then chipped down as near to this line as possible. The casting is then applied to the back head and the high spots noted. These

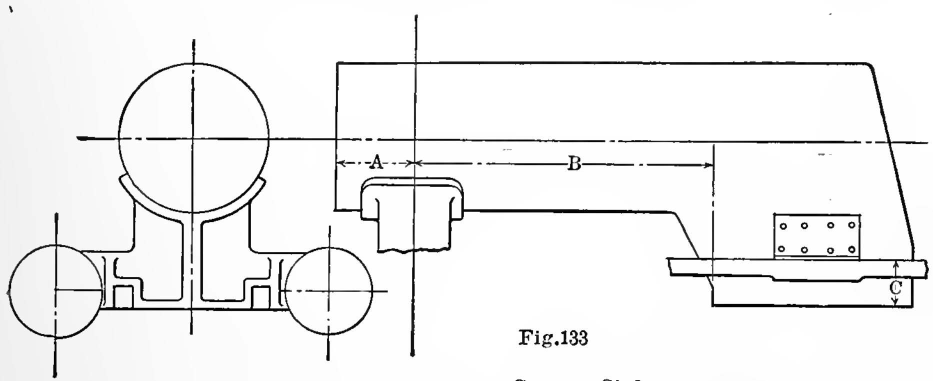


Fig.133

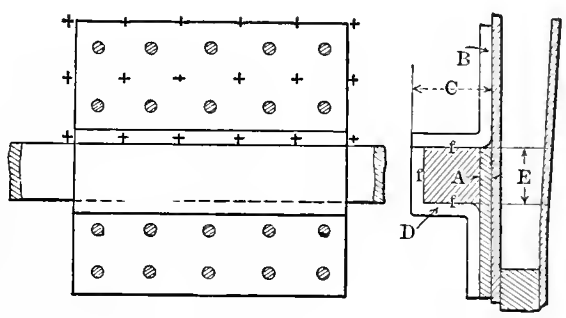


Fig.134

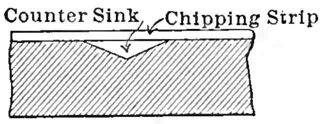


Fig.137

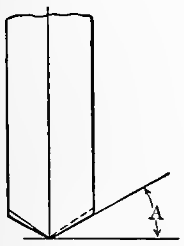


Fig.136

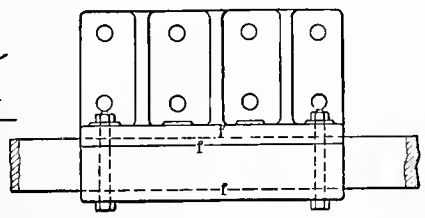
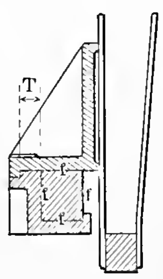


Fig.138



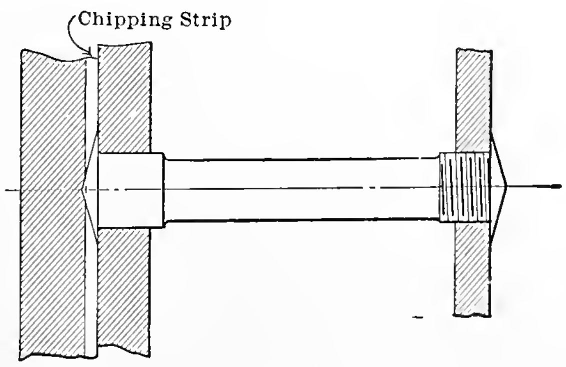


Fig.135

high spots are then chipped and filed until the casting has a good bearing all around.

For the Wootten boilers, and other boilers with wide fire-boxes, the arrangement shown in illustration in Fig. 141 is largely used for supporting the fire-box end of the boiler. *S* is a sheet ½ inch thick, and *L*, *K* and *M* are lugs on the mud ring. These are machined off and the rivet holes *H* are laid off to the dimensions called for on the detail of the mud ring. These holes are then drilled for about ⅞ or 1-inch bolts. *T* is a cross-tie made either of steel casting or steel forging, depending upon conditions, and machined off on the bottom to suit the frame, and on the side to receive the ½-inch plate. The plate is machined off on the lower edge and allowed to rest on the lower frame. This gives a good starting point for laying out the holes on this sheet. The boiler will be lowered into place and blocked up so as to be in perfect alignment. The cross-tie *T* is placed over the frame in position.

The exact location of the cross-tie would depend on the size of the boiler, the amount of expansion, etc. The total expansion and contraction would have to be taken care of by the bending back and forth of this sheet: on the average size boiler about ½ inch would be required. The cross-tie would be located ¼ inch back from the vertical line, so that when the boiler is headed up and in working condition, the lugs on the mud ring would be ¼ inch back from the cross-tie, or the expansion would be about central with this cross-tie.

The locomotive frames at the strongest are very flexible and flimsy sidewise, and for this reason they are tied together with numerous cross-ties, waste sheets, etc. Throughout the whole construction, however, a certain amount of expansion must be provided for.

Fig. 142 shows a waste sheet. There is one or more of these sheets on nearly every boiler. The method of attaching the sheet to the boiler and frames depends somewhat upon the machinery and the parts to be cleared. The illustration is taken from a common construction in use on the average size locomotive. The plate is about ½ inch thick. The knees are machined at *B* for the plate *C*. They are machined to fit the frame. Usually a card accompanies a drawing, showing the size of this sheet. The radius *R* of the sheet is made from ⅛ to ¼ inch larger than the radius of the boiler, so as to admit of ease in fitting up. This sheet is planed along the lower line *D*, where it rests on the knees, and in line central with the boiler.

Scribe off any projection that there may be of the sheet beyond the knees. The bolt holes for securing the sheet to the knees are now scribed off from the knee. While the sheet is being held in position by several clamps, get the waste angle-iron *G*, and try it to the boiler. This will rarely fit up properly without being bent one way or the other. It is often necessary to heat the angle-iron to get it to fit up nicely on all sides. A certain number of equal spaces is laid off along the angle-iron and the holes are punched. In this connection it should be mentioned that punching these holes in the outer leg will distort the angle in some cases, so that it will not fit the boiler. Therefore, these holes should be punched before the angle is bent and fitted to the shell. Having placed the angle-iron in position, and secured it with several clamps, wedge it up at several places tight against the boiler, also wedge the sheet *D* down tight against the knee. Now mark off the holes for the angle on to the waste sheet. If the angle-iron projects, or the sheet projects beyond the angle, lay off a line on the sheet so that when this is sheared off the whole thing will present a neat appearance. Remove the clamps and trim off the extra metal from the sheet. Set the angle-iron against the boiler a little to the front, so that when the boiler is heated up it will stand a little to the back, depending upon the amount of expansion required at this point.

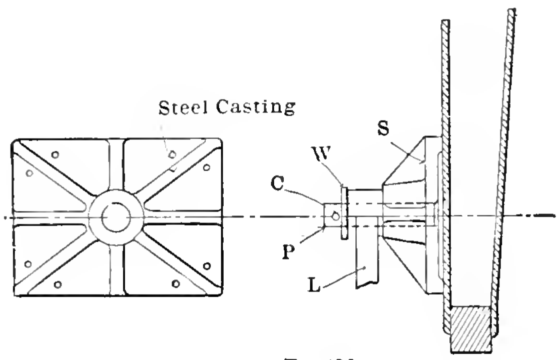


Fig.139

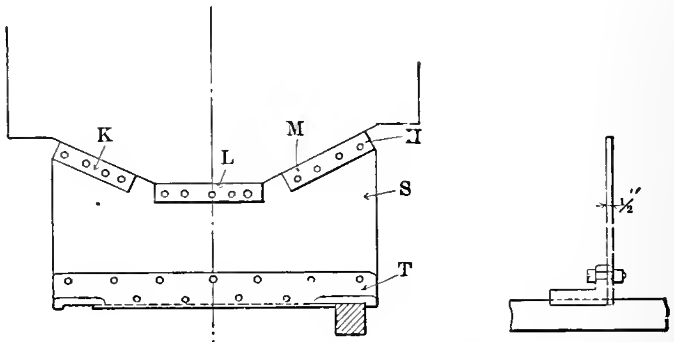


Fig.141

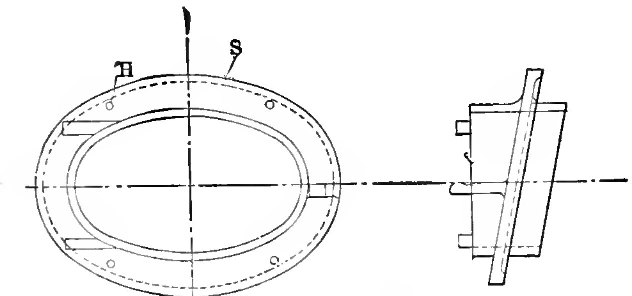


Fig.140

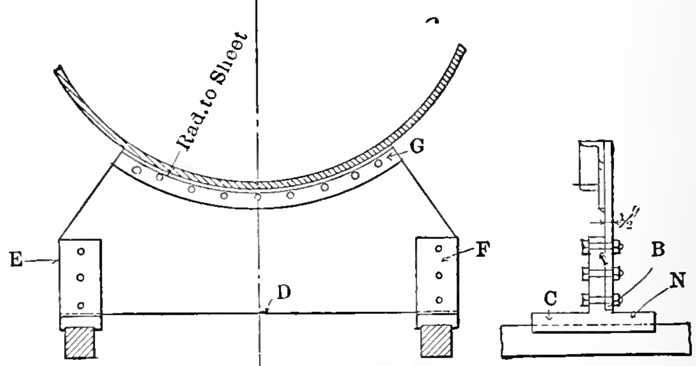


Fig.142

The guide bearer sheet, Fig. 143, rigidly ties together the frames, guide bearer, and boiler. This illustration shows a single sheet extending clear across the guide bearer. This can often be seen on medium size boilers. On very large locomotives the shell comes down close to the frame, so that the guide bearer must be cut out to clear the boiler. In this case two guide bearer sheets will be used instead of one. They are placed out near the end of the guide bearer, and extend

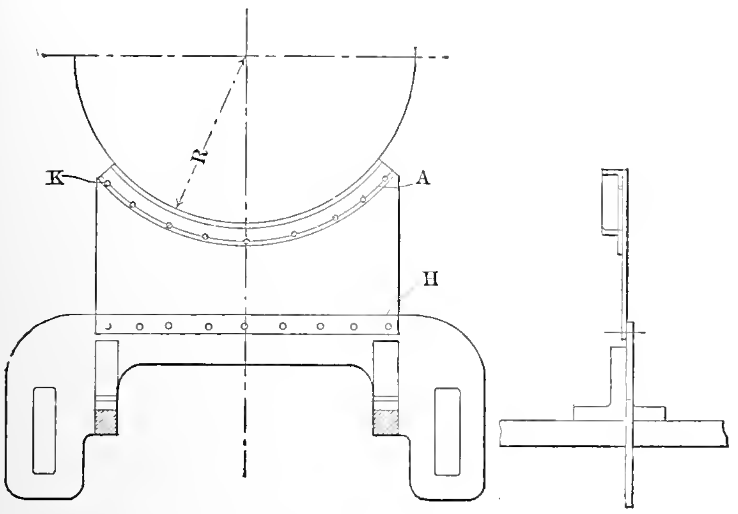


FIG. 143.

in radically against the boiler. The expansion of the boiler at this point is not much. This is a good thing, as these sheets often get to be very narrow, and could not deflect much without straining the parts.

The radius *R* of the sheet is made from ⅛ to ¼ inch larger than that of the boiler. Place the sheet in part against the guide bearer, and fasten it with several clamps. Measure up to see that the projection on either side is the same, and bump the sheet one way or the other so as to bring it central. Mark off the holes *H* from the guide bearer. Place the angle-iron *A* in position. Fit this to the boiler as in Fig. 142, and mark off the holes *K*. Scribe off any projection there may be of the angle beyond the sheet, or of the sheet beyond the angle. The sheet can now be taken down and sheared to these lines, and the holes can then be punched.

CHAPTER IX.

TUBES AND PIPING.

This section deals principally with the tubes and piping. There are many annoying things in connection with maintaining the locomotive boiler in good condition. Not a little of this annoyance comes from the tubes and their setting, and at the joints where the pipes are connected for steam and water. This is largely due to the heavy strain to which the locomotive boiler is subjected. When we consider that a single locomotive boiler can give forth a constant flow of steam to the equivalent of 1,000 horsepower, and then consider the small space occupied by the boiler in comparison with the space occupied by stationary boilers for power plants, it is really a wonder it holds up as well as it does. The fixing up of the tubes consumes a considerable part of a repairman's time. These repairs are largely increased by inferior material in the tubes, and by improper methods of expanding the tubes in position.

Fig. 144 shows the 2-inch tube in position. The tube sheet is shown ½ inch thick. The edge of the copper ferrule should be 1-32 inch back from the fire side of the tube sheet. The scale from the outside of the tube should be removed, so as to form a clean metal joint. The projection of the tube *L* should be 5-16 inch full. The copper ferrule should be clean and true. All the scale should be removed from the flue hole, leaving the metal bright and clean.

The tubes will not all be of the same length, although the front and back heads are parallel. A large number of them, however, will have approximately the same length. With the measuring stick, which has been marked off to scale, begin on one side of the boiler, as at *A*, Fig. 145. Place this measuring stick through the front tube sheet, and through the cone flue hole through the back sheet. Make the proper allowance for beading, as at *A* and *B*, Fig. 146, on each end, and thus determine the length of the tube for this position.

We now shift the measuring stick back and forth and get the length of the next tube. Owing to the irregularities which there will be in the tube sheet, these lengths will vary somewhat, but they can be grouped in sections, each section being marked off, as in Fig. 145, with chalk. After all these tubes have been marked off, it will be found that we will require several batches of tubes. These tubes are then cut to length, those of each batch being kept by themselves. The flues are now put in place and pared out. They must then be expanded with some style of roller expander. The particular form to be used depends upon the success which the particular shop or railroad has had with the different expanders. Expand the tube until it sets firm all around, the copper gasket being by this time about flush with the fire side of the tube sheet. The outer edge is then to be beaded with the regular beading tool.

In beading over the flue, care must be taken to bring the outer edge up tight against the flue sheet, as otherwise the fire will get in behind the bead and burn out the tube. The excessive high pressure carried by many of the large locomotive boilers, together with a forced draft due to the exhaust while running, bring very heavy strain on the flue. The first cost of such a flue is a considerable item, but in some cases it is required, and when the brazing is properly done and a good job is made setting the tubes, the repairs will be considerably less.

Much trouble also arises from the use of poor water. In some localities it is necessary to use muddy water. This mud settles around the tube and thus shuts off the circulation of water. At the same time, the flues, not being in contact with the water, are raised to a higher temperature, thus sooner or later are burned out. In order to get rid of this mud and sediment from the use of hard water, a number of cleaning plugs are placed in the boiler in such a position that they can readily be taken out in order to clean the boiler. Fig. 148 shows the front tube sheet, with the tube admitted at *A*, and in it a brass taper-plug. Holes are also provided on top of the tubes at *B*. In order that a person can get at these tubes with a hose and wash away the accumulation of mud and dirt, a hole corresponding with *A* is usually placed in the opposite

tube sheet, depending upon the location where the boiler is to be used. This affords a clear passage through the boiler and enables one to better see the condition of the tubes. It is not infrequent, however, to have a cleaning plug on one sheet and no hole whatever on the other. The sediment settles in the lowest part of the boiler; where the fire-box is between the frames, the lowest part of the boiler is around the mud-ring, and it is here that the mud collects sometimes in large quantities.

In Fig. 149 is shown a blow-off cock, which should be placed close to the bottom, as shown at *A*. The valve portion is usually cone-shaped. Various methods are used for lifting the cone slightly out of its seat while the valve is being turned on or off. When the valve is shut off, further pressure forces the valve down in its seat and thus makes the joint tight in order to resist the heavy boiler pressure. In some localities

A number of cleaning plugs, Fig. 152, must also be placed on the outside sheet. These should be located in such a position that a hose could be played onto the top of the crown, *C*. These are particularly important, as the crown sheets are usually very flat, and thus afford a good place for the dirt to lodge, and also the seam should be kept clean, as otherwise the excessive heat will burn away the rivets and sheets at this point.

Anyone who has any thing to do with the running of a locomotive boiler knows the difficulties attending the use of hard or muddy water. The mechanical methods for overcoming these difficulties have been pointed out to some extent. Of course one cannot change water conditions very materially, and therefore the boiler maker is obliged to build a boiler which will meet these difficulties. Another source of considerable annoyance lies in the method of getting the

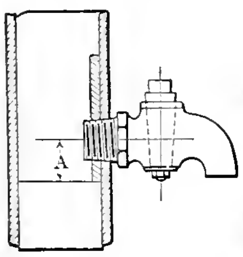


Fig.149

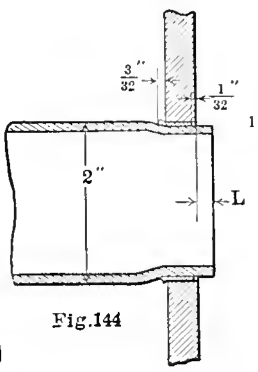


Fig.144

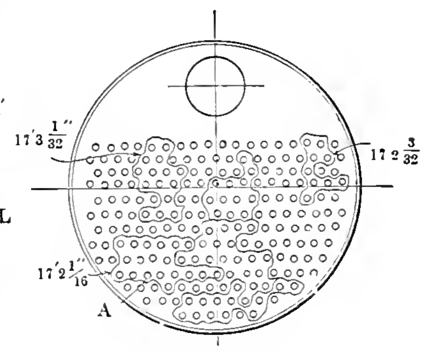
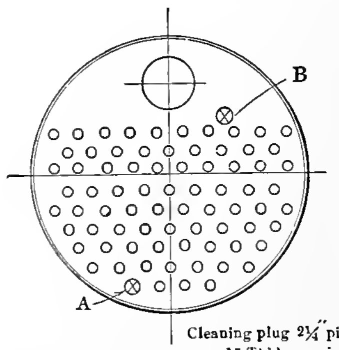


Fig.145



Cleaning plug 2¼" pipe tap 17 Th'ds. per inch

Fig.148

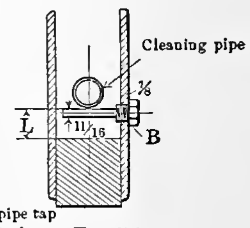


Fig.151

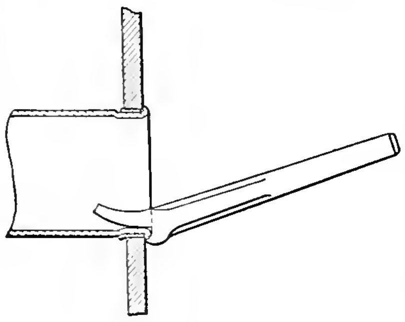


Fig.147

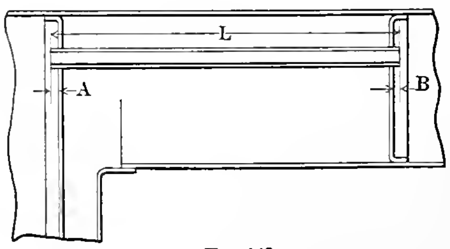


Fig.146

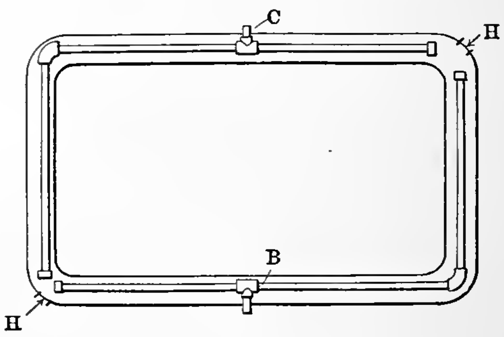


Fig.150

the accumulation of mud in the water space is so great that this blow-off cock will remove only a certain portion of the mud. That which remains settles to the bottom and becomes hard, which is a cause of the side sheets burning out. In order to remove the mud from the bottom of the water space, cleaning pipes, as shown in Fig. 150, are used. Large holes *H* are placed in the corners of the fire-box, and through these holes the cleaning pipes are put in position.

Blow-off cocks are attached at several places, as at *B* and *C*. When these cocks are open, the boiler pressure forces the sediment into numerous little holes which have been drilled in the cleaning pipe, and thus the mud, together with the water, is carried away. The holes *H* are tapped out, and brass taper-plugs are screwed in to close the opening. The pipes must not rest down on the bottom of the mud-ring, but should be supported several inches above the mud-ring, as shown at *L*, Fig. 151. The bolt *B* has a taper thread at the taper, and, the body being turned down to about 11-16 inch diameter, four or five form a sufficient support for the pipe for the one side of the fire-box.

water into the boiler, and this matter must be carefully studied out by the boiler maker.

The general arrangement of feed pipes, injectors, etc., is as shown in Fig. 153. The steam for the injector is taken from the dome through a dry pipe *D*. This pipe must be secured with several wrought-iron strips to the boiler. The upper end *E* should extend to about the level of the intake of the throttle valve. The injector steam valve is connected to the pipe, and from this valve a copper pipe conducts the steam to the injector *J*, Figs. 153 and 154. The copper pipe is sweated to a brass fitting, *F*, see Fig. 155. This fitting is screwed onto the injector, and the joint is made steam tight by grinding the joint.

Be sure that your steam pipe has at least as large an opening at *D* as the steam connection on the injector, so that there will be no lack of steam to force the water. Also be sure that the dry pipe *D* and the injector steam valve *S* have their smallest openings at least equal to the inside diameter of this pipe. Run a copper pipe *C* from the injector to the check, *K*, with a flange similar to Fig. 155 sweated on the pipe at the

injector. No portion of this pipe must have a smaller opening than the delivery end of the injector. Also run a supply pipe *R* from the injector to the rear end of the boiler and connect the same to the hose fitting from the engine to the tender. This pipe is frequently made of copper, but there is a strong tendency toward using iron.

In order to get the exact length and shape for these pipes, block up the injector in about the position called for on the erecting card, and line up properly. Now take quarter-inch round iron wire and bend it so as to lay along the desired center line of the pipe. Mark off the length of the pipe to suit the fittings. In a similar way, bend up a piece for the other pipes. Mark each one of these pieces for the size, class, number, etc., of the boiler. These pipes are then bent to suit these templets and must then be brought to the boiler and tried in position. Any unevenness in the bend, or inaccuracy in shape, can then be corrected.

The injector check is shown in Fig. 156. This illustration shows a brass flange *F,* which is riveted to the boiler and calked tight around the outside. The check is then attached to this flange by four or six studs, and the connection is secured by means of a ground ball joint. The check *C* lifts up and falls by gravity. The valve is usually provided with several guides, which are curved like a screw, so that the motion of the water through the valve will rotate the valve, and thus prevent it from seating in the same place every time. This check should be located along the center line of the boiler, from 20 to 30 inches from the front tube sheet.

Of course, there are a number of other things which the lay-out man has to do on the locomotive boiler. There is the necessary steam pipe and valve for the blower for the air pipe, and for heating. Also, he often has more or less with locating the lubricator pipes, sand-box, bell ringer, etc. Most of these latter details are best taken care of when the locomotive is well under way in the erecting shop, the exact location for the various pipes being settled to suit the convenience of the engineer, etc., and also depending upon the ease with which these things can be put together and taken apart. One can judge the general lines of a finished locomotive better by placing these things on so that they will look right with the other parts of the locomotive.

Thus we have completed, in the limited space allotted, the general lay-out of the various sections of the locomotive boiler. Before bringing this series to a close, however, this one thing should be remembered, that no matter how well things may be described or illustrated for the direction of laying out a locomotive boiler, there is still that large element of judgment, depending upon experience, which will outweigh everything else. It is this personal contact with the actual work of laying out which brings to one that knowledge which enables him to meet these various difficulties of error, of inaccuracy, of defective material, and a hundred and one other things which go together to make a good, substantial, and commercially successful locomotive boiler.

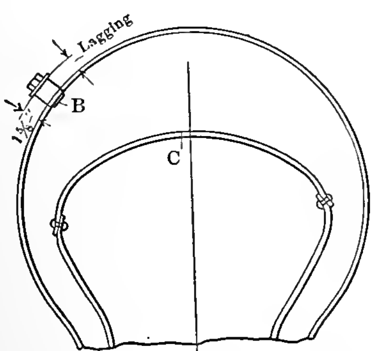


Fig.152

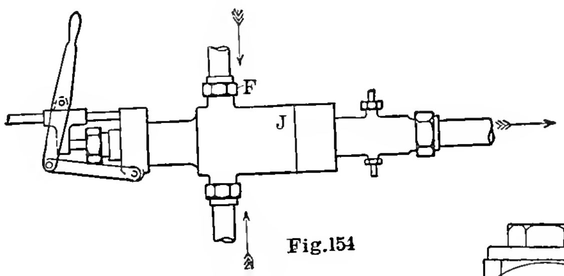


Fig.154

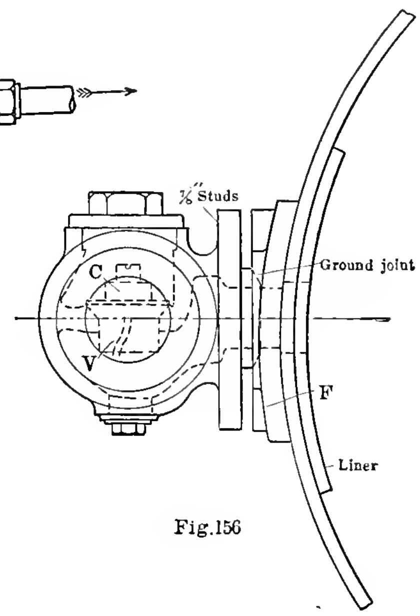


Fig.156

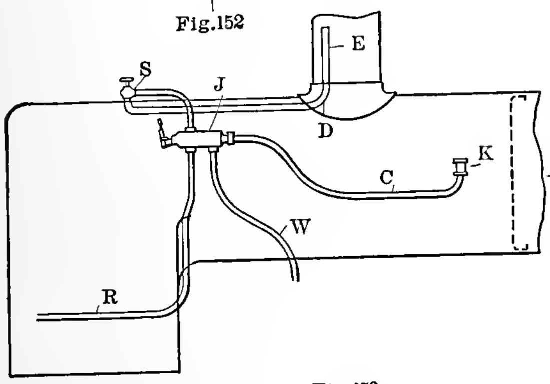


Fig.153

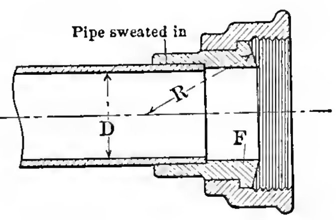
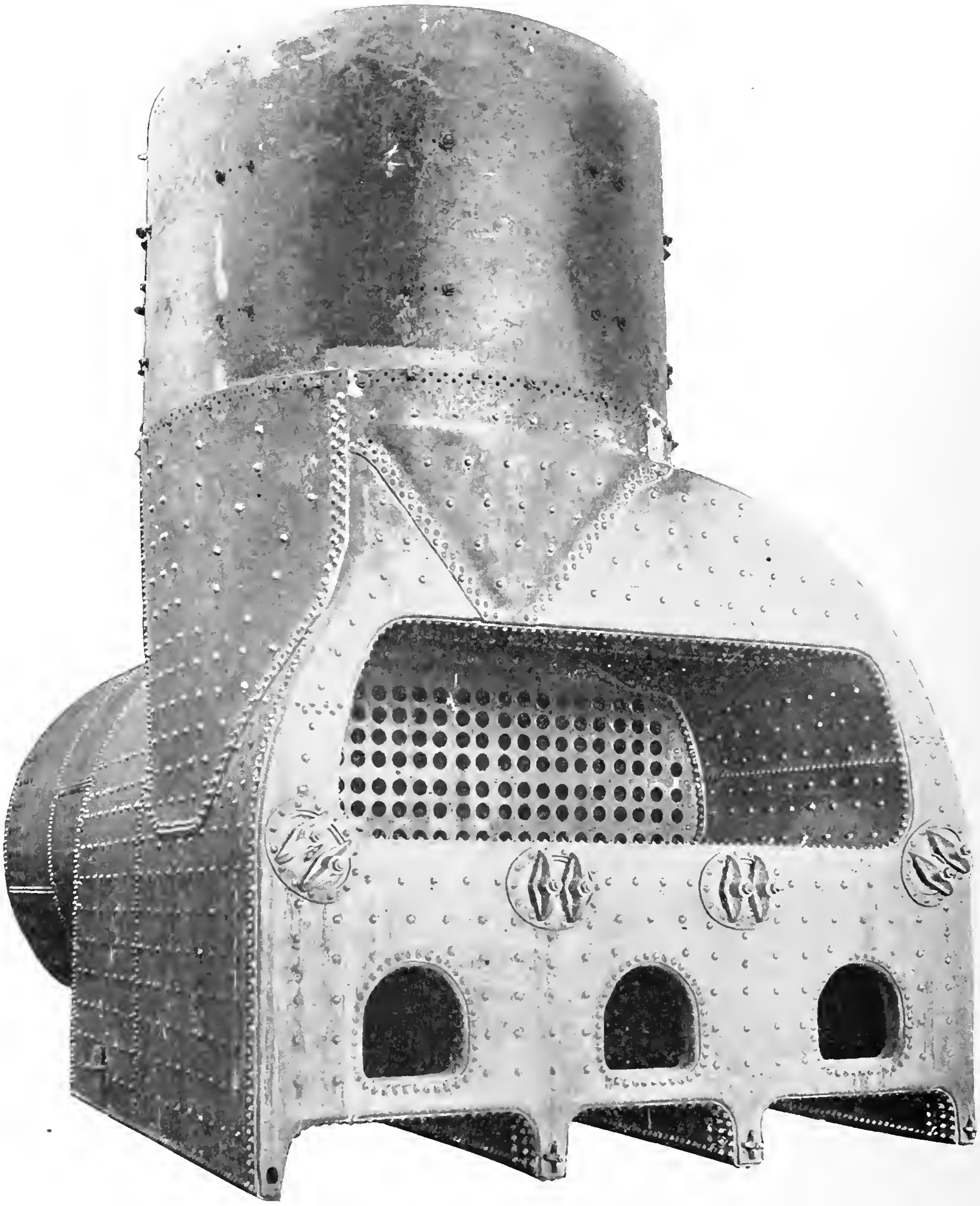


Fig.155

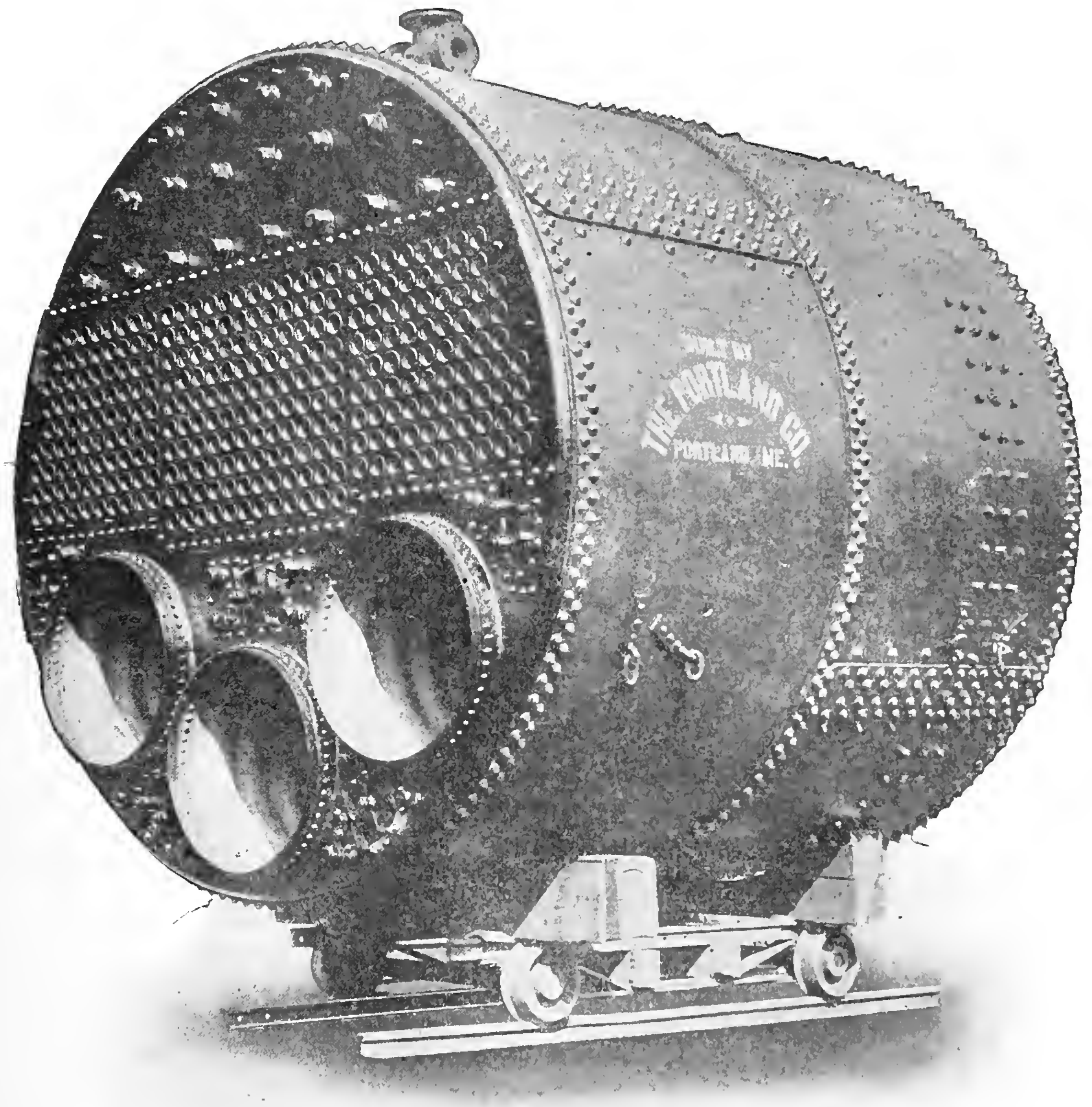


A FLUE AND RETURN TUBULAR MARINE BOILER, 11 FEET 6 INCHES DIAMETER BY 26 FEET 4 INCHES LONG, EQUIPPED WITH SUPERHEATER 9 FEET 6 INCHES DIAMETER BY 19 FEET HIGH; STEAM PRESSURE, 50 POUNDS PER SQUARE INCH; HEATING SURFACE, 3,842 SQUARE FEET; GRATE AREA, 92 SQUARE FEET; RATIO, HEATING SURFACE TO GRATE AREA, 41.9.

HOW TO LAY OUT A SCOTCH BOILER

With boilers as with other things, the tendency of the times has been, and is a survival of the fittest. Of the innumerable classes and types of boilers for the generation of steam for use in marine installations, none has attained the degree of all-around efficiency and excellency as now represented by a modern and well-designed boiler of the Scotch type. This statement applies to a greater or less extent to boilers for stationary uses, although, for reasons of expense principally, the suggestions on the subject of "laying out" a Scotch boiler of an average size, such as might be used for a modern marine plant. To illustrate, suppose we were asked to design a Scotch boiler from the following data, diameter 12 feet 0 inches inside; grate surface, 54 square feet; steam pressure, 175 pounds per square inch. The boiler to furnish steam to a triple expansion engine developing 600 I. H. P.

Of course it is necessary to make a drawing the first thing,



A TYPICAL THREE-FURNACE SCOTCH BOILER.

This boiler is 13 feet 6 inches diameter by 12 feet long. It is fitted with three Morrison corrugated furnaces connected to one combustion chamber, the total heating surface being 2,925 square feet and the total grate surface, with 6-foot bars, 57 square feet. The boiler is designed for 125 pounds pressure.

adoption of this type for land purposes has been confined to very narrow limits. Naturally then the designing of the Scotch boiler for use afloat has been given more attention and has reached more nearly that degree of perfection desirable than has been attained in the designing of this type of boiler for use on shore.

The writer, therefore, in the limited space and time available for the subject, will endeavor to present a few ideas and as the arrangement has to be worked out and the details shown properly, so that a list of all material can be taken off and the material ordered. As the plates will be the first material wanted in the shops, the order for this can be taken off the drawing as soon as the outline is made; ordering the rivets and tubes next, the drawing can then be finished up so that the stays and braces can be ordered.

The first thing in making the drawing is to show the out-

line giving the diameter of shell; this as given is 12 feet 0 inches; after this we want to arrange for the furnaces; as we have 54 square feet to furnish, we see that to put two furnaces in, they would have to be quite large in diameter, so we will arrange for three, making 18 square feet to each furnace; taking out the length of grate of 6 feet (as this is about the maximum length that can be worked efficiently), we would have a furnace of 36 inches inside diameter.

ARRANGEMENT OF FURNACES.

Now we fix the position of the furnaces in the shell, as the diameter is known. Suppose we arrange for a water space between the furnace and shell of 6 inches, less the thickness of furnace (as from experience this seems to give very good results), this would be 6 inches plus 18 inches (half the diameter of furnace), or 24 inches from the inside of shell to center of furnace; as the radius of boiler is 6 feet, the center of furnace will be 4 feet from the center of boiler. If the front end of the furnace is made 36 inches inside diameter, there will be sufficient space between it and the shell to turn the two flanges, one for securing head to furnace, and one for securing head to shell, as shown in Fig. 1. We have now fixed the position of the middle furnace, the center being 48 inches from the center of boiler; with a pair of dividers, draw an arc through the center of middle furnace, extend it up on each side, using the center of boiler for a center; this line will show the distance out for the wing furnaces; now to fix the distance between the furnaces, suppose we made the water space 6 inches from inside of furnace to inside, about what we had between the furnace and shell; this will give a distance of 42 inches from center to center of furnace. We now measure from the center of middle furnace up 42 inches on each side, and where this crosses the 48-inch radius will give us the position of center for wing furnaces. Now we draw in the three furnaces, that is, the three circles showing the inside diameter of each, 36 inches. The positions of the three furnaces are now located in the end view.

SIDE ELEVATION.

We now start on the drawing showing the side view, to fix the length of boiler, furnaces, tubes, etc.

The length of grate we fixed at 6 feet, and allowing for dead plates, bridge walls, say we arrange for a length of tube of 7 feet 3 inches between tube sheets. We then run over it roughly, with this length of tube, to see if we can get the number of tubes in; to give the proper amount of tube heating surface we want to get a total of about 30 square feet of heating surface to 1 square foot of grate surface; the tube surface is usually about 80 per cent. of the total surface. In going over this we find that by using tubes of 2¾-inch diameter we can get them in the length between tube sheets to be 7 feet 3 inches, so the back tube sheet is drawn in at this distance, as shown on the drawing.

The next thing is to arrange for the combustion chamber; this should average about 26 inches, between tube sheet and back head of chamber, as this depth in a boiler of this size gives very good results.

The width of water space back of the combustion box should average about 7½ inches; this will give a water space at bottom of 6 inches, and at the top of 9 inches in the clear, which seems to be ample. With the thickness of plates added to these lengths we find that the length of boiler will be about 10 feet 3½ inches. With this length of boiler we can make the shell plate run from head to head in one piece (as plates of this width can be rolled without very much trouble), thus doing away with the middle circumferential seam, which is a constant source of trouble, by leaking at the bottom, due to expansion and contraction.

There is a great difference in temperature between the water in the top and that in the bottom of a Scotch boiler, especially so on first starting fire and getting steam; if the fires are forced to get steam quickly, when steam has formed, the water in the bottom will be comparatively cold.

While making the shell plate reach from head to head adds materially to the life of a Scotch boiler, it does not add to the cost and is a much better job throughout. It does away with one long seam, the working under of butt straps and many rivets.

As we have the length of boiler now, we can draw in the outside of each head and shell, connecting the outside of lower heads with the inside of shell plate with a 3¼-inch radius,

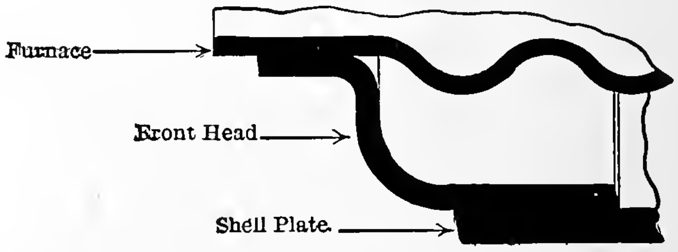


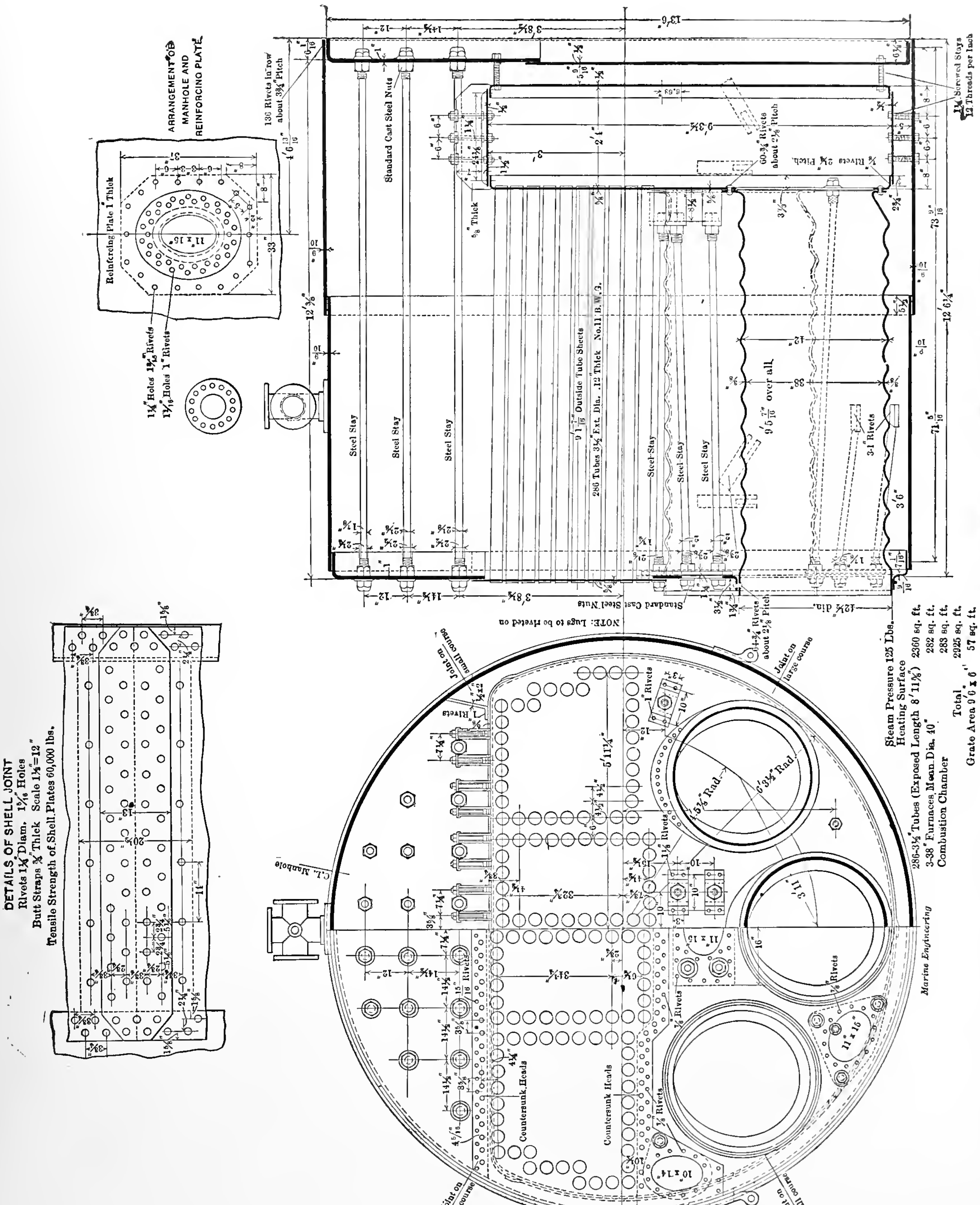
FIG. 1.

and the top head with a 2½-inch radius; as it is customary to make the top of heads heavier on account of the bracing, we arrange to put the top part of head on the inside of bottom part, as shown.

The lower part of heads we will make ¾-inch thick, the back tube sheet ¾-inch thick, and the combustion chamber plates all 9-16-inch thick; all inside laps should be arranged for single riveting; the calculations for thickness of plates and the riveting will be shown later, the idea being to have the drawing in outline, and then go over all the calculations when this is finished.

We have located the position of the back tube sheet, so will draw it in, arranging to turn the top flange down (for top plate of combustion chamber or wrapper) at a distance from center of boiler of 31¼ inches; this gives a space between top of combustion chamber and top of shell of approximately 28 per cent. of the diameter of boiler, which is about as small as can be made with good results; should it be made any smaller it would decrease the water surface and steam space of boiler.

We now have the top of combustion chamber located, and the bottom is fixed by the bottom of furnaces, so we can pencil in the back sheet, which is 6 inches in the clear from the back head at bottom and 9 inches in clear at the top; this head is flanged, using a radius of 1½ inches.



DETAILS OF THREE-FURNACE SINGLE-ENDED SCOTCH BOILER WITH COMMON COMBUSTION CHAMBER SHOWN ON PAGE 105.

ARRANGEMENT OF TUBES.

We now have the location of combustion chamber in the side view of boiler; we will arrange for each furnace to have a separate combustion chamber, so will start to draw them in on the front view of boiler. We draw in the line showing the top 31¼ inches up from the center line of boiler, and roughly arrange the tubes to see just where the wide water spaces will be (between the nests of tubes); in the center nest, we find that we can get 7 vertical rows, that is, over the middle furnace.

Over the wing furnaces we find that we can get 10 vertical rows over each; this will give us 85 tubes in the middle nest and 86 tubes in each wing nest, making a total of 257 tubes.

The tubes are arranged with a space of 1 inch between them, vertically, and 1¼ inches horizontally, making the pitch 3¾ inches vertically and 4 inches horizontally. The tubes forming the wide water space are spaced 14 inches from center to center; this allows a water space between the plates of combustion chambers above furnaces of 6¼ inches, the center of

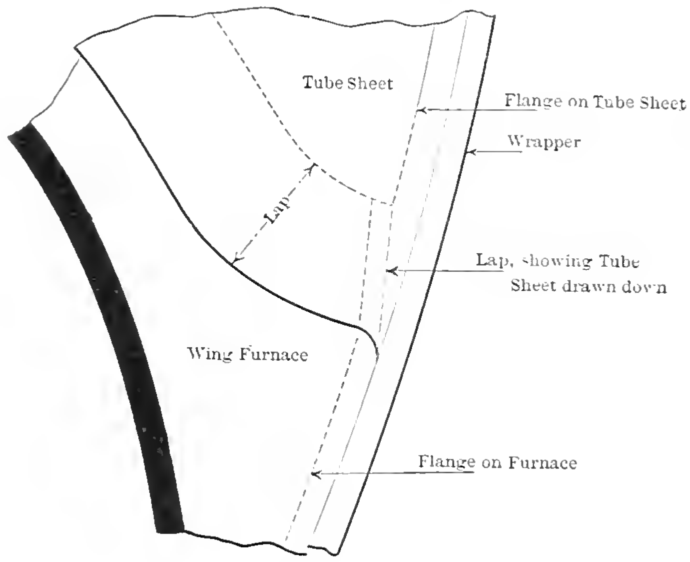


FIG. 2.

outer rows being 3 5-16 inches from the inside of these plates. The outside of wing chambers is formed by a radius of 65¾ inches, drawn from a center 1¼ inches below center of boiler, as shown, and runs into the back end of furnaces forming a fair curve for the wrapper. By dropping this center below the center of boiler the water space between it and the shell increases toward the top and does not reduce the number of tubes.

Connecting the outside corners to top with a radius of 4½ inches, and the inside corners to top with a 3½-inch radius, we have the outline of box as shown.

The combustion chambers are now outlined in this view; the next thing to do is to show in the tubes.

These we fixed 2¾ inches in diameter; from the top of tube-sheet flange we measure 3 7-16 inches down and draw a line parallel to it; this will be the center line of top row of tubes, and as we have the pitch we can draw in the outline of tubes.

In arranging tubes in a boiler care should be taken not to place the tubes too near the furnace crowns, as there should be a good space over the furnaces to insure solid water there, when forcing the fires.

The space between the tubes and furnace crowns should never be less than that shown on drawing above wing furnaces.

BACK CONNECTIONS.

The back ends of furnaces, where they are flanged up to join the tube sheet, are shaped as shown to make a fair line for the outside plate of combustion chamber. As the tube

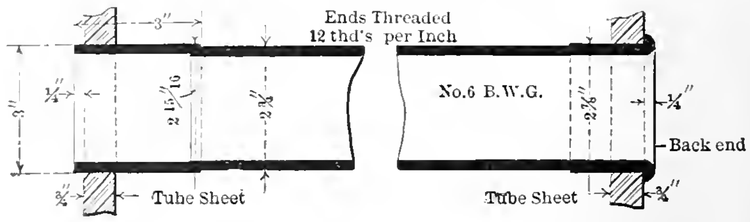


FIG. 3.

sheets are placed between the furnace flange and wrapper, it is scarphed down to a feather edge and the furnace flange bent back to allow it to go in between, as shown in Fig. 2.

The back end of furnace is flanged up back of tube sheet to keep the flame from striking directly on the calking edge of joint, as it enters the combustion chamber over bridge wall.

The joints of wrapper or outside plate of combustion chamber are arranged, as shown where they lap on the tube sheet and back head of combustion chamber, the inside plate is flanged down to a feather edge, so as not to have a thick body of metal there and to form a good calking edge. Where there are three thicknesses of metal, in combustion chambers especially, one must be drawn down as thin as practicable, as it is hard to keep a joint tight where the temperatures are so high, as in back connections, if the laps are too thick.

STAY TUBES AND PLAIN TUBES.

In boilers carrying high pressures it is necessary to make some of the tubes thicker than the ordinary ones; these are called stay tubes, and are fitted to stay the tube sheets. Stay tubes are fitted in different ways; some are plain, heavy tubes, some are threaded and fitted with nuts, others are threaded,

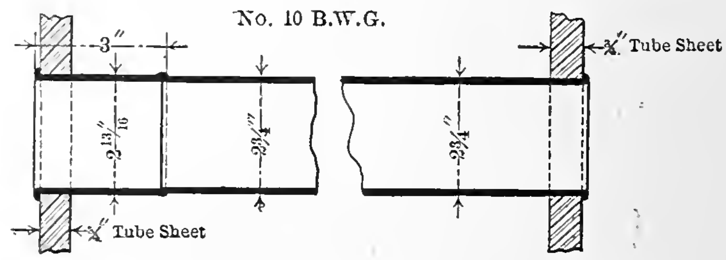


FIG. 4.

the back end having a parallel thread and the front end a taper thread, both raised above the outside diameter of tube, the tube is screwed into the tube sheets, expanded, and the back end beaded over as shown in Fig. 3.

The plain tubes are generally swelled at the front end; this necessitates a larger hole in the front tube sheet than that in the back one and permits passing the tube through the front tube sheet into the back one without any trouble in forcing it through. These tubes, after placed in position, are expanded or rolled into the tube sheets, the ends beaded over. (See Fig. 4.)

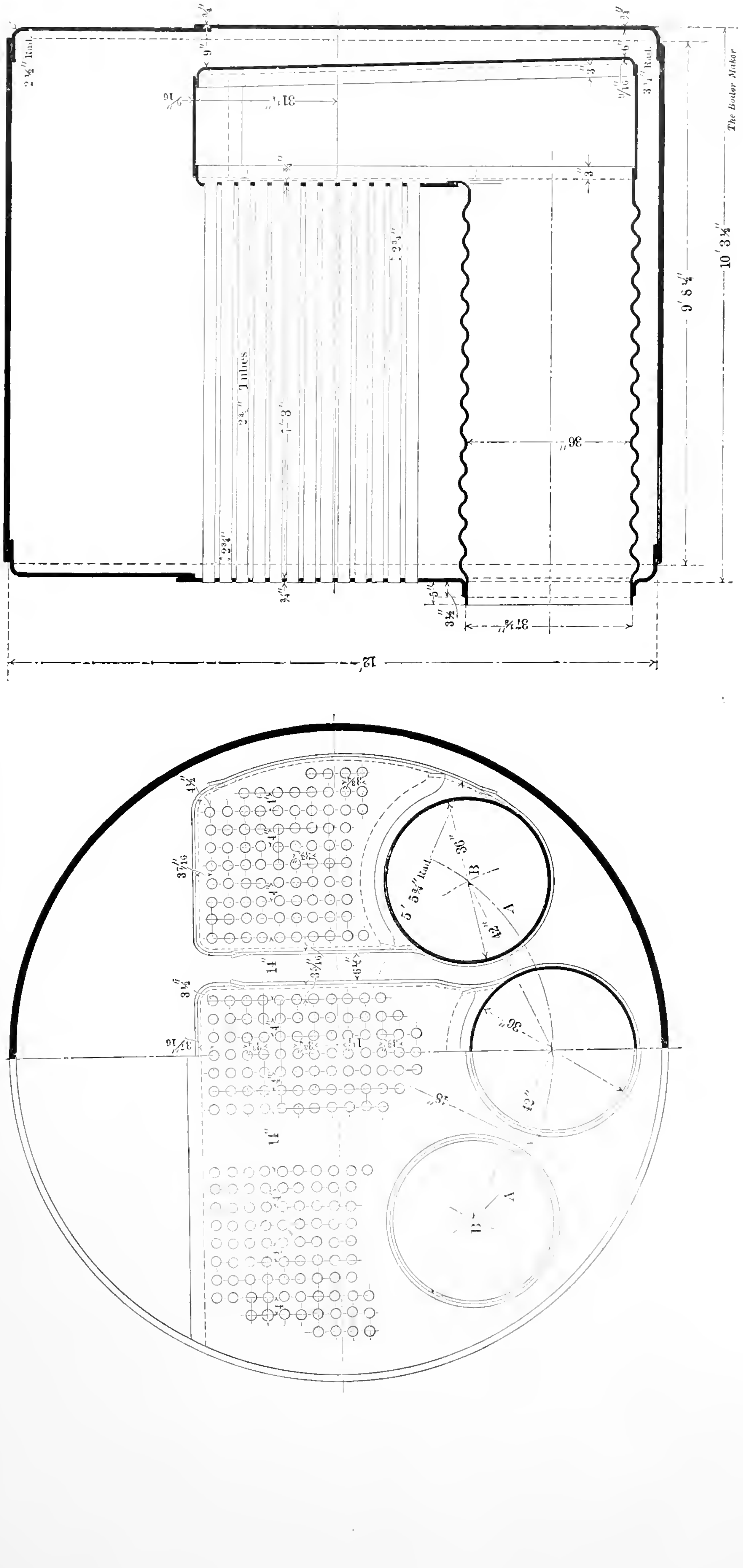
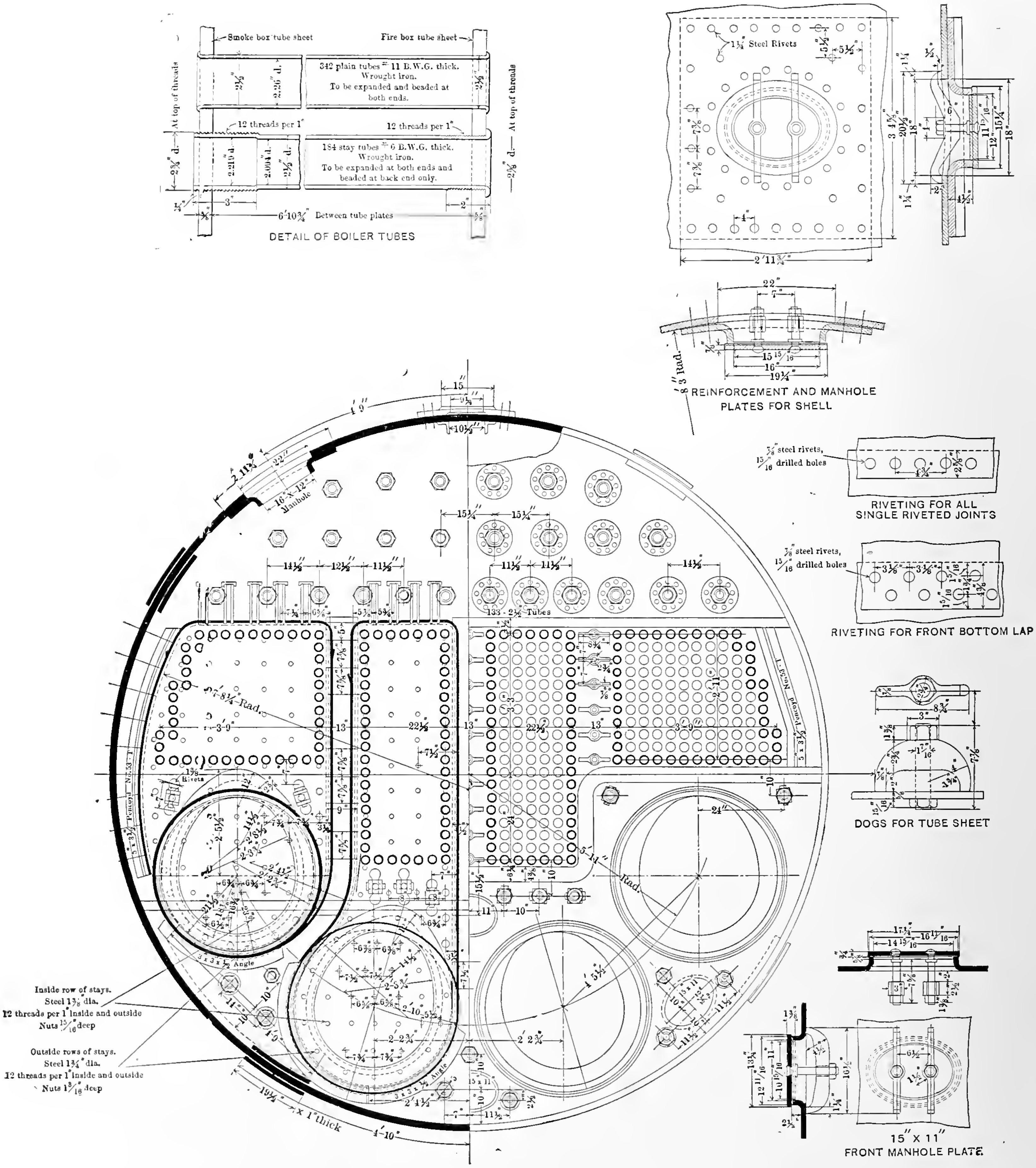
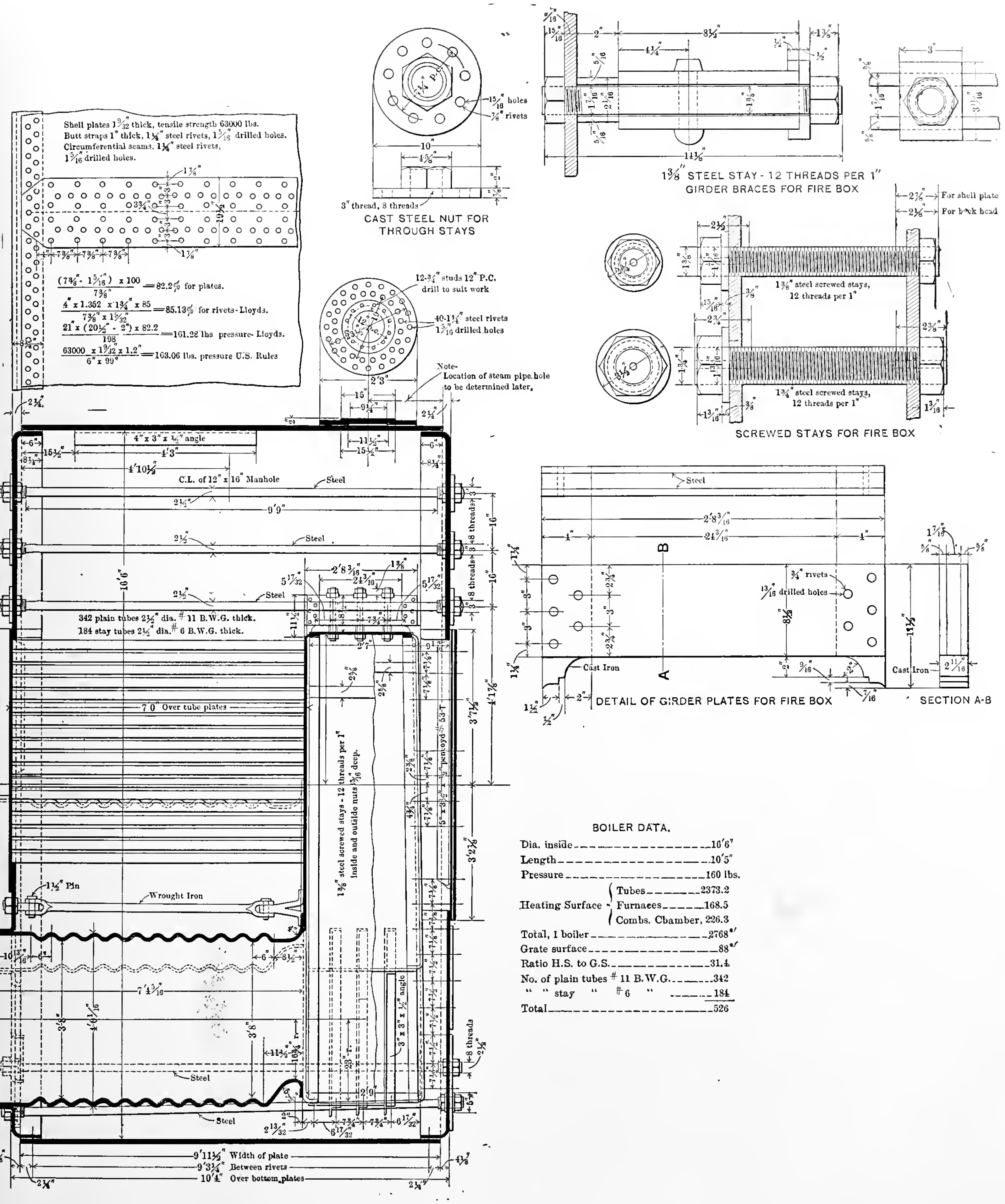


DIAGRAM SHOWING THE PRELIMINARY WORK IN LAYING OUT A SCOTCH BOILER.



HALF CROSS-SECTIONS AND DETAILS OF TUBES, MANHOLES AND HANDHOLES OF A MODERN, FOUR-FURNACE, SINGLE-ENDED SCOTCH BOILER, 16 FEET 6 INCHES DIAMETER BY 10 FEET 4 INCHES LONG.



LONGITUDINAL SECTION AND DETAILS OF RIVETING AND STAYING OF A MODERN FOUR-FURNACE, SINGLE-ENDED SCOTCH BOILER, 16 FEET 6 INCHES DIAMETER BY 10 FEET 4 INCHES LONG.

SHELL PLATES

Now to fix the thickness of the shell plates, suppose we provide for a tensile strength of 66,000 pounds per square inch. The first thing to do now is to decide on the style of joint to be used. Suppose we settle on a butt joint, using double straps.

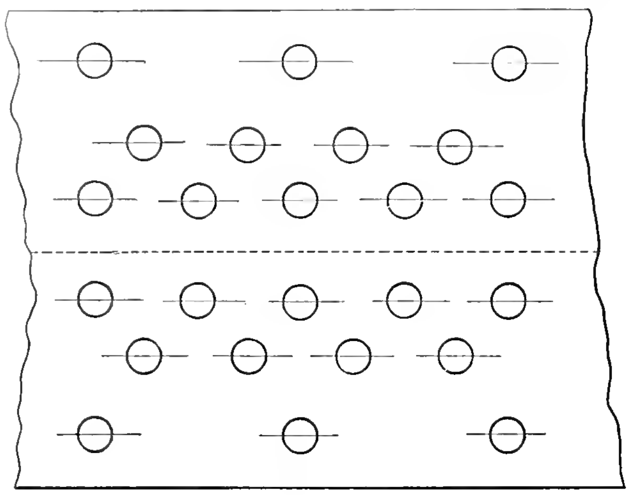


FIG. 5.

with three rows of rivets on each side, leaving out every other rivet in the outer rows as shown in Fig. 5.

The formula for the strength of cylindrical steel shells is as follows:

$$\frac{C \times (T - 2) \times B}{D} = WP$$

C is a constant, and for this style of joint is 20. T is thickness of material (shell plate) in sixteenths of an inch. B is the least percentage of the strength of joint, of rivet and plate sections, which in this case we have arranged for an 84 per cent. joint. D is the mean diameter of shell in inches; WP is the working pressure. Now to transfer the formula to get the thickness of shell, for 175 pounds per square-inch steam pressure, we would write it thus—

$$T = 2 + \frac{175 \times 144}{20 \times 84} = 17$$

that is 17-16 or 1 1-16 inches thick for the shell plate.

The percentage of strength of joint is found as follows: Where p = pitch of rivets, d = diameter of rivet, n = number of rivets in the pitch, T = thickness of plate in inches, and where rivets are in double shear 1.75 is used.

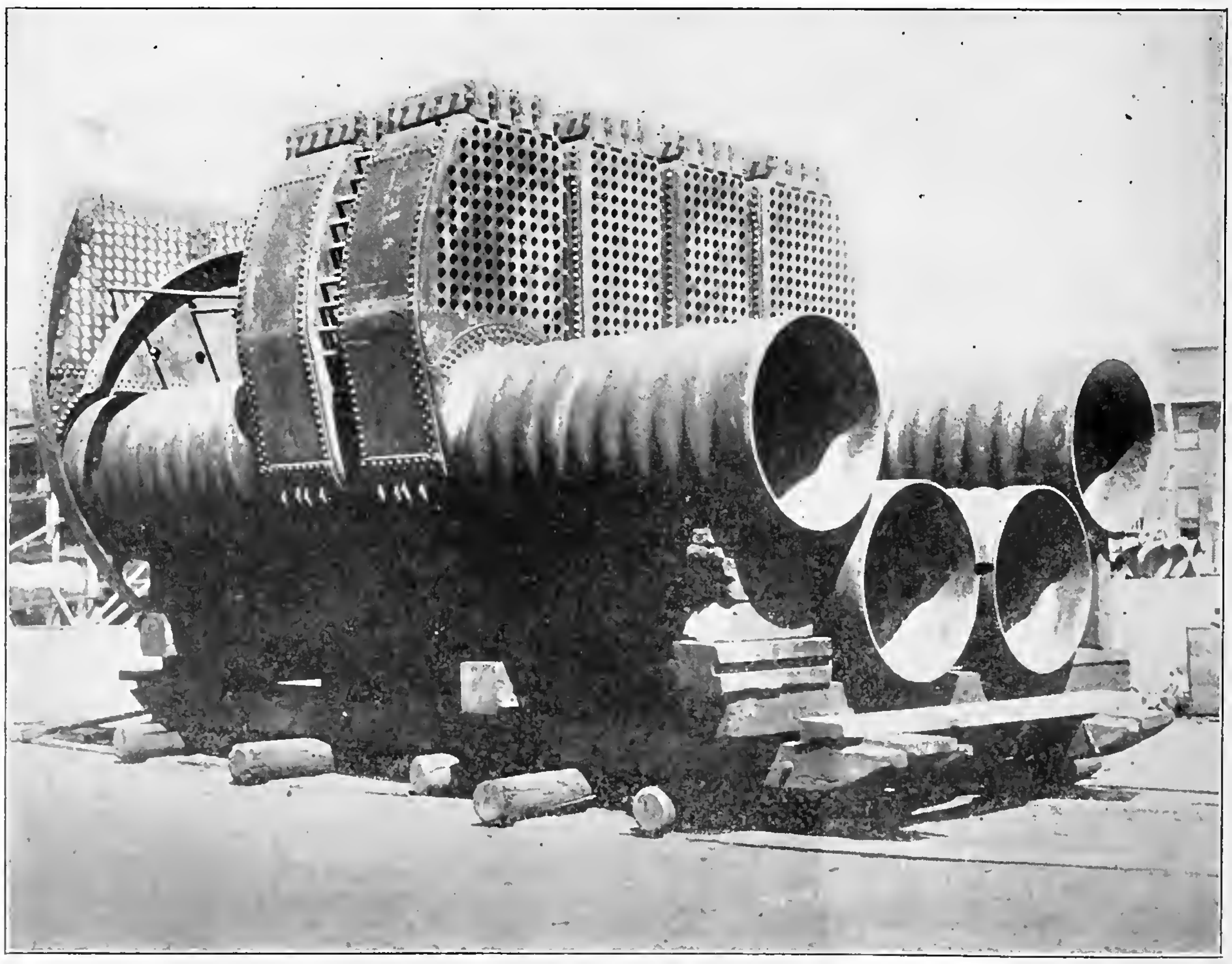
As we have arranged the riveting for a pitch of 7 1-16 inches, and the rivet holes to be drilled, 1 1-16 inches diameter, the percentage of strength of joint for plate will be found by the following formula:

$$\frac{(p - d) \times 100}{p} = \text{per cent. of joint} = \frac{6 \times 100}{7.0625} = 84.9 \text{ per cent.}$$

The percentage of strength of joint for the rivets will be found by the following:

$$\frac{23 \times d^2 \times .7854 \times n \times 1.75}{28 \times p \times T} = \text{per cent.} = \frac{23 \times 1.1289 \times .7854 \times 5 \times 1.75}{28 \times 7.0625 \times 1.0625} = 84.9 \text{ per cent.}$$

As the rivet material is usually softer than that of the shell,



COMBUSTION CHAMBERS AND FURNACES FOR AN EIGHT-FURNACE DOUBLE-ENDED BOILER.

and subjected to a shearing strain, a ratio of 28 to 23 is taken, making an increase in rivet section over that of the plate; this ratio, it will be observed, is used in the above formula.

The factor of safety is found by the following:

Tensile strength of shell × thickness of shell × strength of

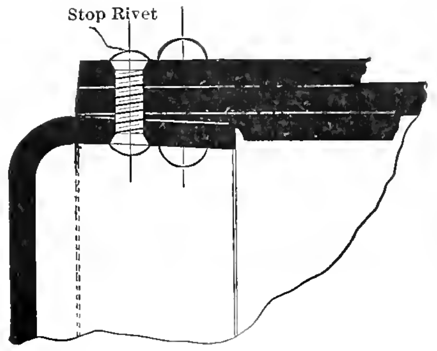


FIG. 6.

joint per cent. ÷ steam pressure in pounds per square inch × radius of shell in inches =

$$\frac{66{,}000 \times 1.0625 \times .849}{175 \times 72} = 4.7 \text{ factor of safety.}$$

BUTT STRAPS.

The butt straps should be at least ⅝ times the thickness of the shell plates, and are often made of the same thickness. The straps should be rolled at the mill so that the grain runs the same as the shell plates, as there is enough difference to warrant this. We will make the butt straps in this case ⅞ inch thick, and to extend the full length of the shell on the outside, the inside straps to be drawn down and fitted under the flange of head and shell plate, as shown in Fig. 6.

A stop rivet, to be fitted at the end of each butt strap, as shown in the sketch, Fig. 6, and on the sketch showing the riveting for butt straps, the hole will be tapped with a fine thread tap and a bolt (special) screwed in and riveted over with a countersink inside and outside, this is used as a stop-water for the butt of the shell plates. There is usually

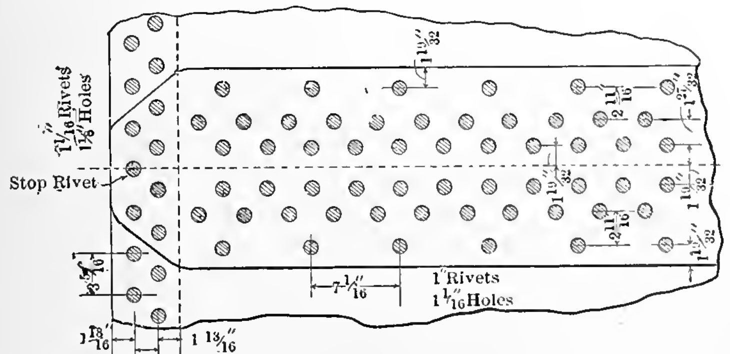


FIG. 7.

considerable trouble in making the ends of butt straps tight, due to the expansion and contraction of the plates: the stop rivet seems to help this trouble, although not a sure cure.

CIRCUMFERENTIAL SEAMS.

The end or circumferential seams will be double riveted, using 1 1-16-inch rivets, the holes being drilled to 1⅛ inches diameter, the center of the holes will be 1 13-16 inches from the edge of plates. The distance between the rows of rivets will be 1 25-32 inches, center to center. This will make a lap of 5 13-32 inches. The pitch will be 3 5-16 inches. This arrangement of riveting will be used for securing the upper and lower part of heads to shell plate.

The rivets for butt straps will be 1 inch in diameter, the holes drilled 1 1-16 inches, the pitch 7 1-16 inches, every other rivet in the outer rows being left out, the spacing of the rows will be, for outside row, 1 19-32 inches from edge of plate to center of rivet, from this to center of next row 2 11-16 inches, to the next row 1 27-32 inches, and to edge of plate again 1 19-32 inches, the same arrangement will be made on the other side of joint, as shown in Fig. 7.

MANHOLE.

A manhole plate will be fitted in the shell, as shown on the drawing. This must be located to give ample room for getting in and out of the boiler between the through braces in steam space. The opening cut in shell for manhole will be stiffened by a wrought steel plate 30 inches by 33 inches by 1 1-16 inches thick; it will be flanged in and planed off to form a face for the plate to bear on. Care should be taken in

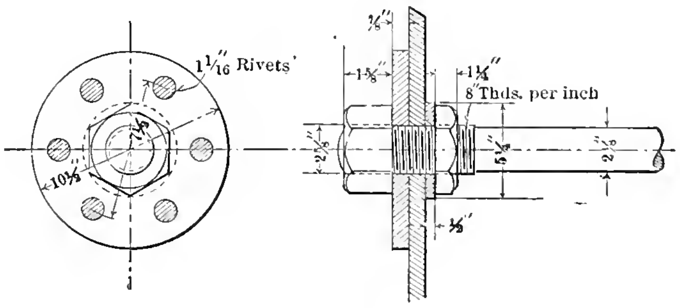


FIG. 8.

flanging the metal over to keep the proper thickness for the face for joint, as the metal is likely to stretch and be too thin on the edge if not properly worked.

The opening in this plate will be 12 inches by 16 inches in the clear, and it will be so arranged that the short diameter will be in the length of boiler, in order to cut out as little as possible of the shell plate, in a fore and aft direction.

This plate is shaped to fit the inside of shell plate, as shown, being calked on both sides.

The plate shown is made of wrought steel, being grooved to hold the packing and fit over the flange of stiffening plate; this style of plate is very good and not hard to make if the proper tools are at hand. The plate bolts are 1 3-8 inches in diameter, having collars forged on, as shown, the bolts are screwed into the plate and the ends riveted over into countersinks and calked. If an eye-bolt is fitted to the plate between the two bolts, it will be found a great convenience in handling the plate, as it can be held in place, the dogs dropped over and the nuts set up, with very little trouble, as the tendency of the plate to slip from its original position is thus overcome. Plates are not usually fitted with these eye-bolts, but the cost is trifling, as compared to the time and labor otherwise necessary when taking the plates off and replacing them.

LOCATING BUTT STRAPS.

In locating the butt straps for shell, care should be taken to arrange them to clear the seams on head above tubes, and the screw stays, from the combustion chamber through shell on bottom. If it is found that the stays will have to pass through the lower straps, they should be arranged, if possible, to pass through rivet holes, to avoid cutting extra holes in the shell plate.

The straps, located as shown on this drawing, clears the seams and screw stays too, but it will not always work out so.

THROUGH STAYS.

In locating the through stays in steam space, they have to be far enough apart for a person to get between them for cleaning, repairs, examinations, etc. The through stays in this case we have arranged to pass through the heads, washers being riveted to head for each stay, the outside nuts setting up on the large washers; thin nuts and washers will be fitted to the plates on the inside (see Fig. 8). The ends of these stays are to be swelled or upset for the thread. As we

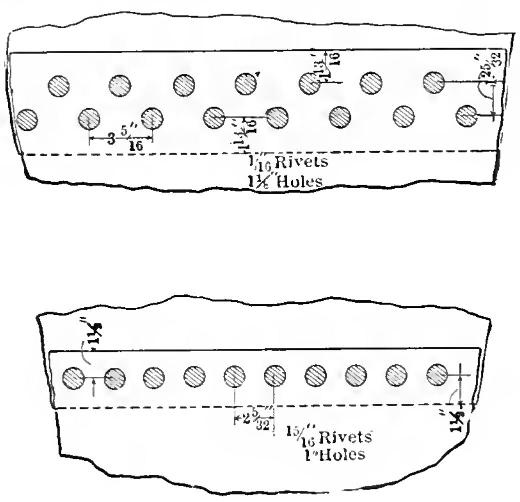


FIG. 9.

have arranged to make the upper part of heads ⅞ inch thick, and to fit ⅞-inch thick washers for stays, we can now get the spacing the stays should be from the following formula:

For washers the same thickness as plate and 2-3 the pitch for diameter =

$$\frac{\text{Constant} \times \text{thickness of plate}^2\text{, in sixteenths of an inch.}}{\text{Working pressure}} =$$

$$\sqrt{\text{Pitch}} = \frac{220 \times 196}{175} = \sqrt{246.4} = 15.7 \text{ inches.}$$

The constant in this case is 220.

We find that we can space these stays 15.7 inches from center to center, or call this 15⅝ inches.

Taking the top row of stays of the combustion chamber for the back head and the top row of tubes for the front head, we find that we can place the first row of through stays 8¼ inches above the flange of back sheet or head of combustion chamber, and the next row 15⅝ inches above this. In spacing them the other way, we have to arrange to suit the tops of combustion chambers, the crown bars and water spaces between the tubes. In arranging them in this case, we locate two on the center line, one above the other, and 14 inches each side of this we locate two more, then 14½ inches from these two we locate two more, and 14½ inches from these we locate one more in the lower row. Now, to find the load on each stay, we find that the maximum surface for one stay to support is 14.5 inches by 15⅝ inches, making 226.5 square inches, this multiplied by 175 (the steam pressure carried) gives a total strain or load of 39,648 pounds, and to arrange for the stress on the stay not to exceed 9,000 pounds per square inch, we divide 9,000 into 39,648, which gives a result of 4.4 square inches area.

To give 4.4 square inches area we find that we will have to use a stay 2⅝ inches diameter with 8 threads per inch. This diameter need only be at the ends where the thread is cut; the body of the bolt can be of less diameter, just so that it does not give an area less than 4.4 square inches. Where

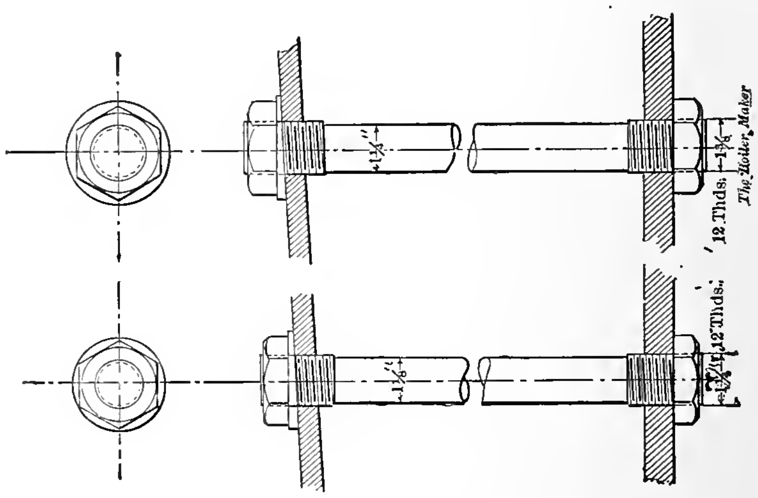


FIG. 10.

a thread is cut the area is always taken at the bottom of the thread. The body of these bolts we find can be made 2⅜ inches diameter.

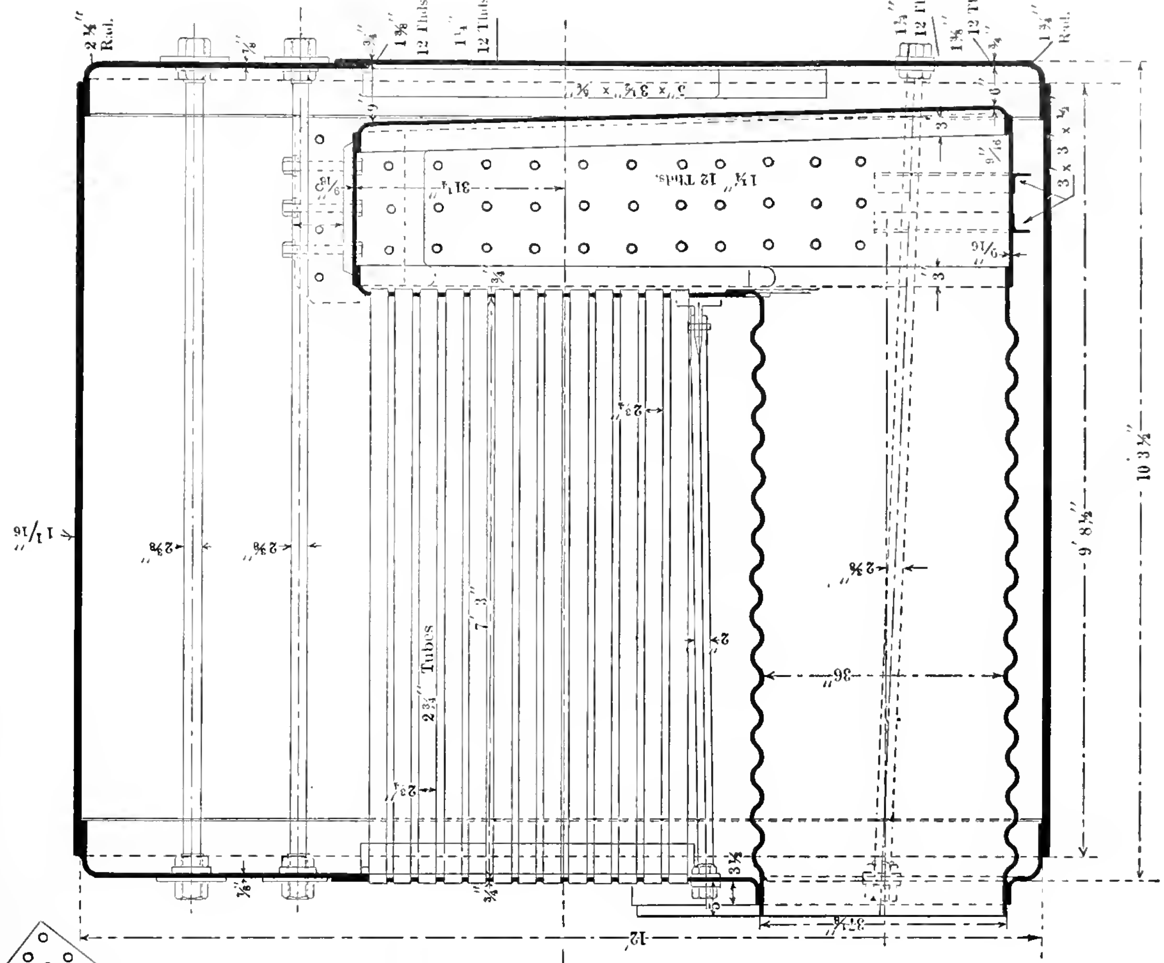
It is not often that fine threads are cut on these stays, as coarse threads are better.

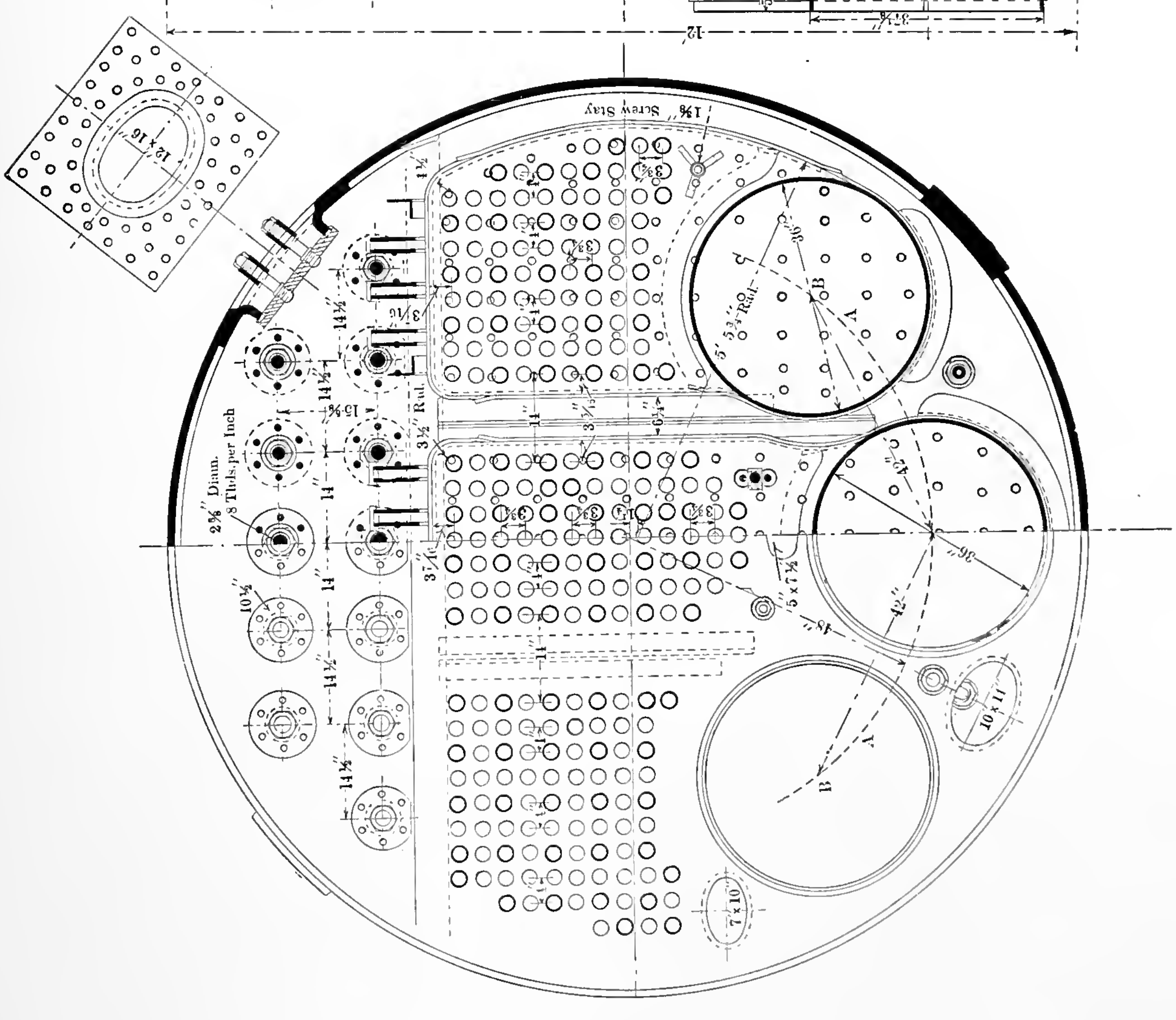
A loose washer is usually fitted under the inside nut; this is counterbored to hold packing, and held up in place by the inside nut, as shown.

The outside washers we have made 10½ inches diameter by ⅞ inch thick and riveted to the head by six 1 1-16 inch rivets, on a pitch circle of 7½ inches. To give space to calk the washers and seams on heads, a portion of the lower outside washers is cut away, as shown on the drawing of the boiler.

The laps of the heads are double-riveted, as shown in Fig. 9, and located near the tubes in front, and stays at top of combustion chambers in the back head. The top section of heads being on the inside, the lower parts are scarped down at the lap; for shell, this should be done very carefully, so that no unnecessary shaping will be required to the shell plates over these laps, as the shell plate should not be heated unless they are annealed after being operated upon.

The rivets securing the two sections of front head will be arranged to be driven flush on the outside, as this saves considerable trouble in fitting the smoke box or uptake, if the stays and nuts are to be outside of the box.





The upper part of uptake will have to be secured to boiler about over this cross-seam in front head of boiler, and if the rivets are not arranged for and driven flush, considerable trouble is found in making the connection.

BACK HEAD.

The wrapper and back heads of combustion chambers are made of plates 9-16 inch thick and single riveted, as shown above.

This style of joint is used for all the single riveting throughout the boiler. The plates are stayed with 1⅜-inch and 1¼-inch screw stays, 12 threads per inch. (Fig. 10.)

The 1⅜-inch, 12-thread stays are fitted all around the edge of back heads of combustion chambers, as these help to stiffen up the wide spaces on back head.

All the stays on back heads of combustion chambers inside of the row of 1⅜-inch stays are 1¼-inch diameter, 12 threads per inch; the stays through the wrappers are also 1¼-inch diameter, 12 threads per inch.

To divide the space up for stays, we find that they will be spaced about 6¼ inches by 6¾ inches; this gives a surface of 42.18 square inches, and this multiplied by 175, the steam pressure carried, will give a strain or load for one stay of 7381.5 pounds, which is a strain just over 7,000 pounds per square inch; as the ends of these stays are in the fire, it is well to keep the strain low.

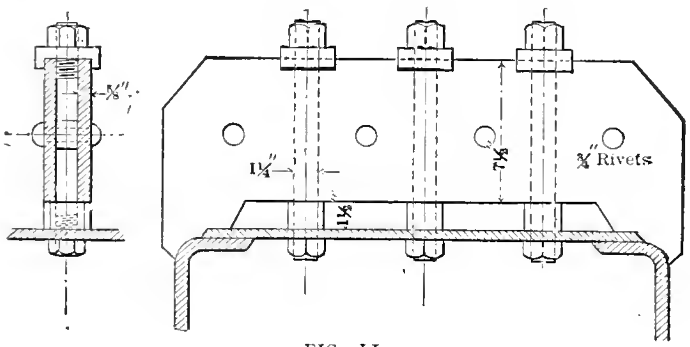


FIG. 11

These stays are tapped through the back head square, and do not require a washer under the nuts. The inside nuts, on account of the angle of plate, will require beveled washers fitted under them, so that they will set up fair.

Washers should be fitted only where they cannot be avoided, on the fire side, as they only act as a non-conductor, and the liability of the nuts burning is increased.

The holes for stays are tapped out in place, with a special tap, so that they will be in line, and the thread continuous in both plates.

The stays are turned down between the plates, as shown, as it is found that corrosion is much more liable to occur at the bottom of the V-shaped threads than it is on cylindrical surfaces.

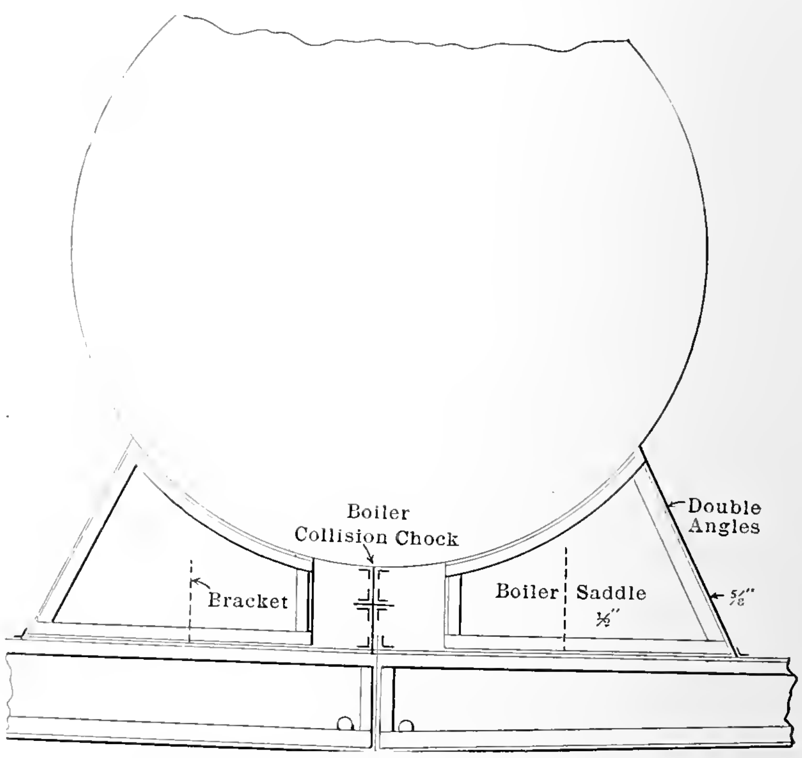
After the stays are fitted in place, the plates are calked around each stay, and the nuts screwed up tight. The nuts should be about ¾ inch thick, for if too thick there is a chance of their being overheated, and another of starting the thread in the plate when setting up on the nuts.

The stays should not extend through the nuts, but should be just flush with the face of same; if fitted in this way, the nuts can be removed with much less trouble, in case they have to be taken off for repairs. Ordinarily, they would have to be cut off, on account of the stays extending out through the nuts and becoming burned.

BOILER SADDLES.

Care should be taken in arranging the boiler saddles to see that the screw stays are not covered up, as it would make repairs troublesome. These stays should not be spaced too far apart, as the plates are liable to bulge between them, especially so on the back head of combustion chamber, where the flame strikes after it passes over the bridge wall. Seams should never be located in this part of the head, as they will always give trouble if the fires are forced much.

The crowns of combustion chambers are usually stiffened by girders, with bolts through them, as shown in the sketch above.



ORDINARY TYPE OF SADDLE FOR SCOTCH BOILER.

The girder, as shown above, is made of two ⅝-inch plates riveted together, using sockets to keep them apart, and the ends cut to fit the combustion chamber, as shown in Fig. 11.

The bolts are tapped through the crown, calked and fitted with nuts on the fire side. The upper ends pass through a spanner, with a nut on top. A socket is placed between the bottom of girder and crown, so that the stays can be set up solidly.

The inboard and outboard ends of wing combustion chambers have an angle stiffener or girder fitted to them, as there is a small area of the plate to be supported, but not enough to require a full girder.

It is desirable to keep the crowns as clear as possible, so that the plates will be thoroughly protected by the water, and access given for cleaning.

The bottoms of combustion chambers are stiffened by two angles, 3 inches by 3 inches by ½ inch, riveted to the plates and extended up, as shown.

ORDERING MATERIAL.

The next step necessary is to make up the schedule of material for plates to send off to the mill.

As to the furnaces, they are not made by the boiler builder, so a drawing is made of each, showing exactly what is desired and giving the exact diameter where they are to fit into heads or flanged openings.

All the work on the boiler can be progressed and arranged to suit the furnaces even if they have not been received.

The furnace manufacturer is very careful to get the furnaces just as close to what the drawing calls for as it is possible to get them, knowing sometimes that all the work is finished (flanged) ready for the furnaces.

It is customary for the furnace manufacturer to order the plates for his work, so that the boiler builder does not order this material.

We will now prepare the list of material for the plates of the boiler. The requirements for the material are about as follows:

The tensile strength of shell plates to be not less than 66,000 pounds per square inch, with an elongation of not less than 22 per cent in 8 inches. The elastic limit not to be below 35,000 pounds.

The bending test will be made on a piece about 2 inches wide by 12 inches long, cut from each plate; this test piece must bend cold around a curve, the diameter of which is equal to the thickness of plate, until the sides of the piece are parallel, without showing signs of fracture on the outside of bend.

The requirements for the material marked "flange and fire-box" are about as follows:

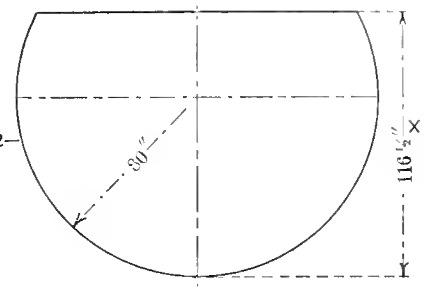
The tensile strength will be from 52,000 to 58,000 pounds per square inch, with an elongation in 8 inches of not less than 28 per cent.

The bending test will be made on a piece cut from each plate, about 2 inches wide and 12 inches long; it will be heated to a cherry red and quenched in water about 82 degrees F. The piece must then bend over flat on itself without showing cracks or flaws.

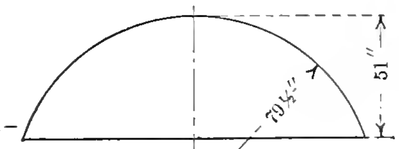
When ordering plates for boiler work, an additional amount equal to the thickness of plate should be added to each end, and one-half the thickness to each side, as the shearing injures the material, and by allowing this margin to be planed off in the boiler shop, the damage caused by the shearing is removed.

LIST OF STEEL PLATES FOR BOILER.

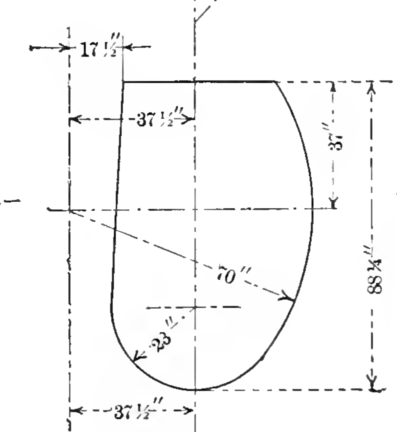
No.	Dimensions.			Quality.	Purpose.
2—	230"	× 117½"	× 1 1/16"	Shell.	.Outside shell.
2—	17½"	× 117½"	× ⅞"	"	..Butt straps (shell).
2—	17½"	× 116"	× ⅞"	"	..Butt straps (shell).
1—	34"	× 30"	× 1 1/16"	"	..Manhole stiffening plate (shell).
1—	17"	× 21"	× 1⅜"	"	..Manhole plate (shell).
24—	11½"	Diam.	× ⅞"	"	..Washers (through braces).
1—	68"	× 39½"	× ¾"	"	..Back tube sheet (middle).
2—	24"	× 51"	× 9/16"	Shell.	.Wrapper comb. chamber.
2—	26½"	× 64"	× 9/16"	"	..Wrapper comb. chamber.
2—	27"	× 111½"	× 9/16"	"	..Wrapper comb. chamber.



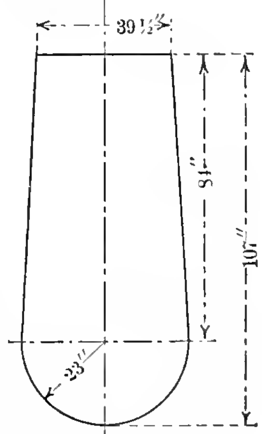
2— × ¾" "Flange and fire box" Lower part of heads



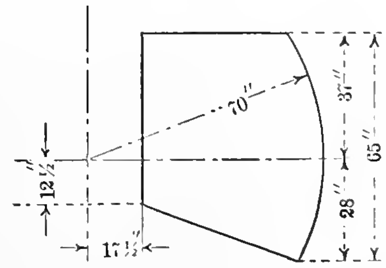
2— × ⅞" "Flange and fire box" Upper part of heads



2— × 9/16" "Flange and fire box" Back heads wing comb. chambers



× 9/16" "Flange and fire box" Back head middle comb chamber



× ¾" "Flange and fire box" Back tube sheets (wing)

No.	Dimensions.			Quality.	Purpose.
1—	24"	× 49"	× 9/16"	Shell.	.Wrapper comb. chamber.
1—	27½"	× 204"	× 9/16"	"	..Wrapper comb. chamber.
20—	11"	× 28½"	× ⅝"	"	..Girders.

This finishes up the plate order, the next step is to prepare the rivet order.

The requirement for the rivets will be about as follows:

The rivets for butt straps to shell will have a tensile strength of not less than 66,000 pounds per square inch, and an elongation of at least 26 per cent in 8 inches.

Other rivets to have a tensile strength of from 52,000 to 58,000 pounds per square inch, and an elongation of 29 per cent in 8 inches.

All rivets to be of open-hearth steel and true to form:

No.	Dimensions.			Purpose.
225—1″	diam.	× 4 5/16″	long	Butt straps (shell).
70—1″	"	× 3½″	"	Manhole stiff. (shell).
250—1 1/16″	"	× 3⅜″	"	Head to shell (top).
350—1 1/16″	"	× 3¼″	"	Head to shell (bottom).
185—1 1/16″	"	× 3 1/16″	"	Across heads.
150—1 1/16″	"	× 3 3/16″	"	Washers on heads.
490— 15/16″	"	× 2⅜″	"	Combustion chambers.
175— 15/16″	"	× 2 5/16″	"	Furnaces to wrapper.
225— 15/16″	"	× 2 9/16″	"	Tube sheet to wrapper.
75— 15/16″	"	× 2⅜″	"	Tube sheet to furnace.
185— 15/16″	"	× 2½″	"	Furnaces to front head.
150— ⅞″	"	× 2 9/16″	"	Angles to heads.
80— ⅞″	"	× 2¼″	"	Angles to comb. chamb.
50— ⅞″	"	× 3⅞″	"	Girders.

The practical tests for rivets are: (rivets taken from the keg at random) first one rivet will be flattened out cold under the hammer to a thickness of one-third the diameter, without showing cracks or flaws.

One to be flattened out hot under the hammer to a thickness of one-fourth the diameter, without showing cracks or flaws, the heat to be about the same as used to drive the rivet.

One to be bent cold flat on itself without showing cracks or flaws.

Having completed the list of rivets we will now take up the

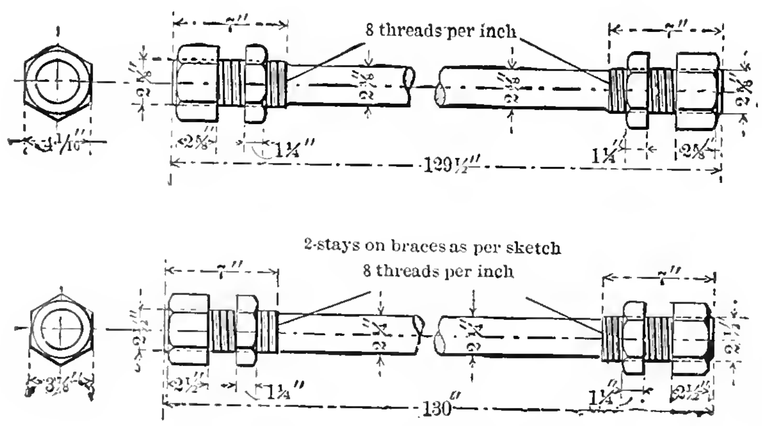


FIG. 12.—STAYS OR BRACES AS PER SKETCH.

braces, screw stays and nuts and prepare the order list.

The requirements for this material will be about as follows:

The tensile strength of the through braces will not be less than 66,000 pounds per square inch, and an elongation in 8 inches of not less than 22 per cent.

The bending test will be made on a piece ½ inch square cut from a bar, and must stand bending double, cold, to an inner diameter of 1½ inches, without showing cracks or flaws.

The two stays to the crow feet over the middle furnace are to be of iron with a jaw welded to one end for a pin to crow foot, and a thread on the other end fitted with nuts and washers for securing to the front head. It is customary for most boiler makers to make these stays themselves, although some have them made outside; if they are made outside, a sketch is sent them to work from.

We will now make up the schedule for material for the screw stays. As it is customary to order the material for these stays in long lengths, we will order the number of feet required and have it made up from standard bar lengths.

The threading and cutting to length is done in the boiler shop, the exact length being taken from the work. It is also necessary that the threads at both ends be made continuous.

The requirements for this material are about as follows:

The tensile strength to be from 52,000 to 58,000 pounds per square inch, and an elongation in a length of 8 inches of not less than 29 per cent.

The bending test will be made on a piece ½ inch square, cut from the bars, and must stand being bent double to an inner diameter of 1½ inches, after being quenched in water about 82° F. from a dark cherry red heat in daylight, without showing cracks or flaws.

105 feet 1⅜ inches diameter in stock lengths.
284 feet 1¼ inches diameter in stock lengths.

As this completes the order for the screw stay material, we will next prepare an order list for the nuts for the screw stays.

Nuts to be hexagonal, faced square and tapped.

200—1⅜″ tapped 12 threads per inch—1″ thick, 2 3/16″ across flats.

610—1¼″ tapped 12 threads per inch—⅞″ thick, 2″ across flats.

60—1¼″ tapped 12 threads per inch—1¼″ thick, 2″ over flats.

We will now make up the order for the angle stiffeners, the

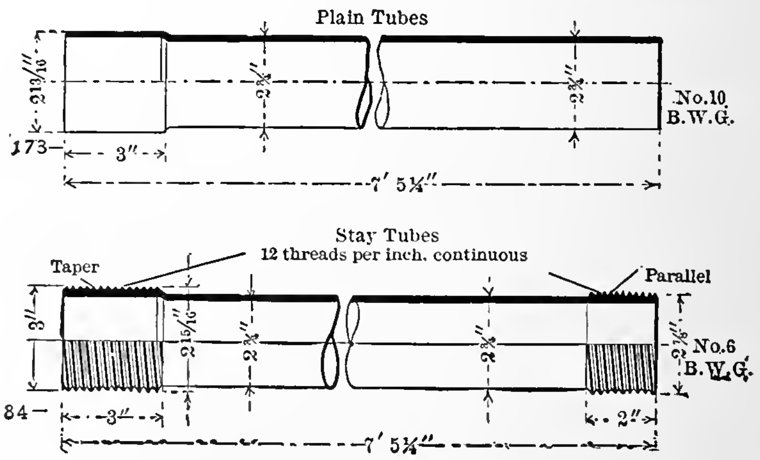
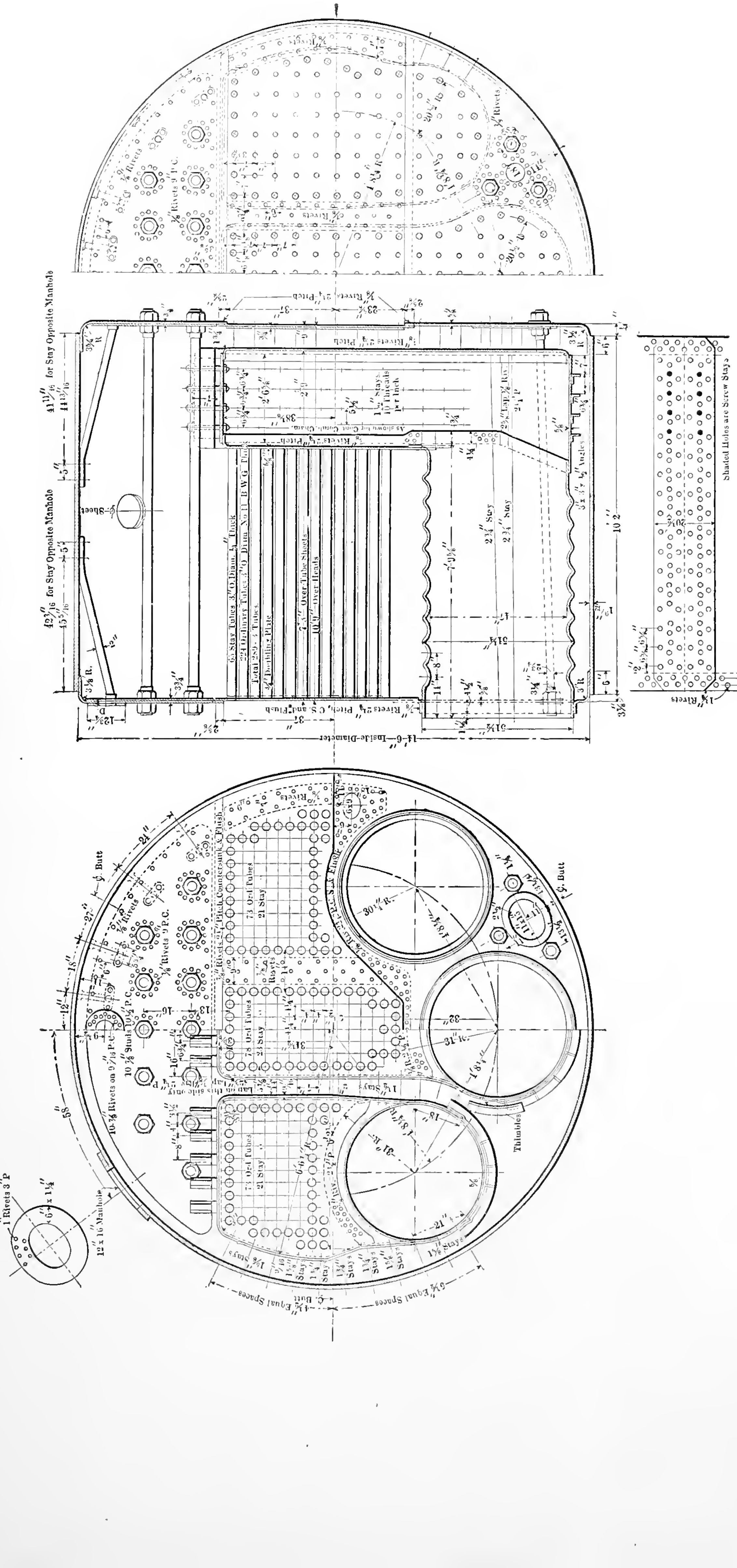


FIG. 13.

requirements for these angles will be about the same as that for the screw stay material:

2—pieces angle	3½″	x 5″	x ⅝″	x 56″	long.
2— " "	3½″	x 5″	x ⅝″	x 51″	"
2— " "	3½″	x 5″	x ⅝″	x 75″	"
2— " "	3½″	x 5″	x ⅝″	x 58″	"
2— " "	3″	x 3″	x ½″	x 62″	"
4— " "	3″	x 3″	x ½″	x 30″	"
4— " "	3″	x 4″	x ½″	x 30″	"

It is customary for the boiler maker to make the small washers, crow feet, etc., and to have patterns for manhole and handhole plates, dogs, etc., if they are to be castings. The next to



A THREE-FURNACE SCOTCH BOILER, 11 FEET 6 INCHES DIAMETER.

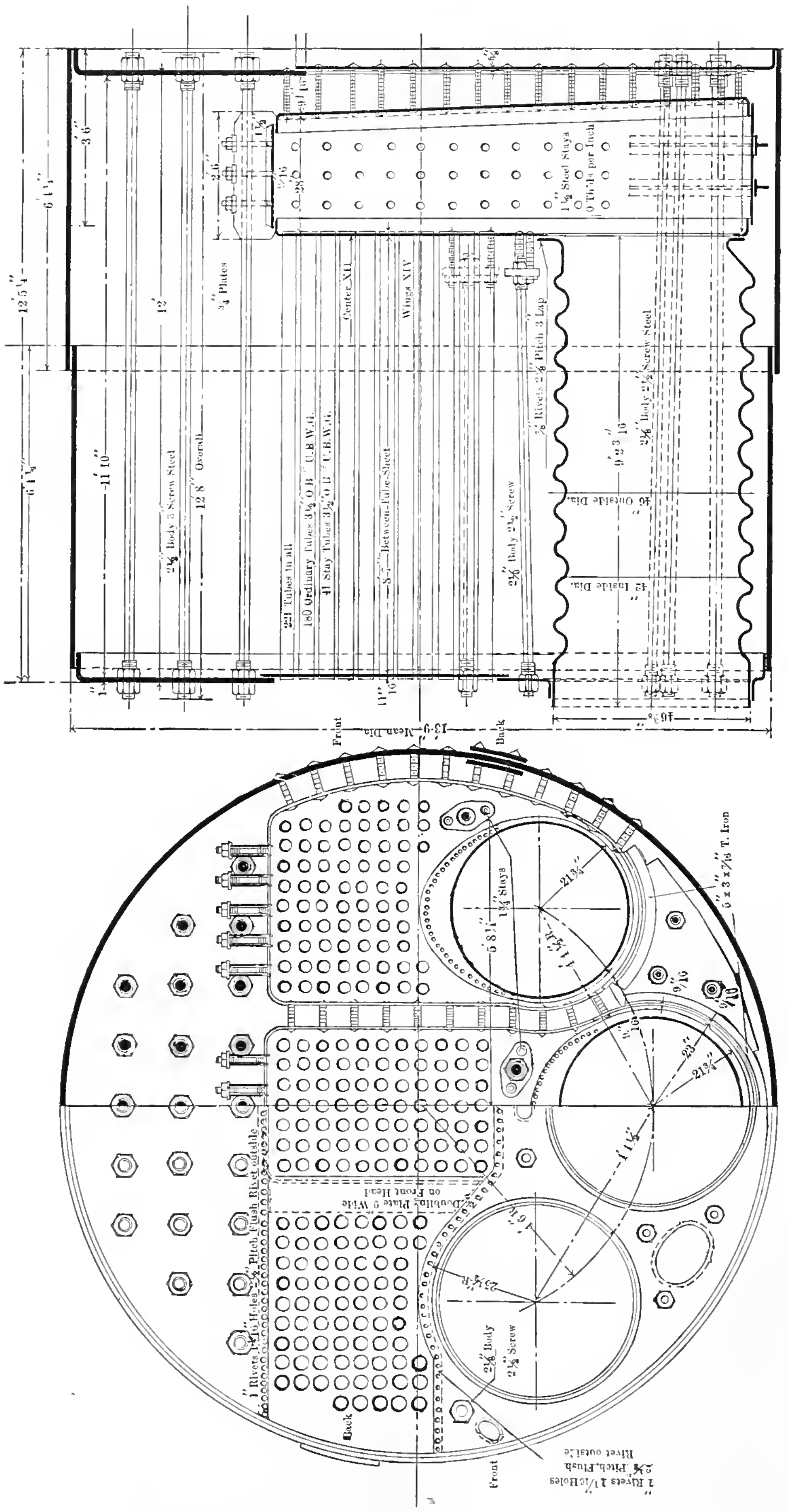
make up, is the list or order for the tubes. These are to be made of low carbon mild steel and uniform in quality and grade.

They will be of seamless, cold-drawn steel, 2¾ inches outside diameter, the ordinary tubes of No. 10 B. W. G. in thickness. The stay tubes will be 2¾ inches outside diameter of No. 6 B. W. G. in thickness. The stay tubes will be threaded at each end, as shown on the accompanying sketch (Fig. 13).

The requirements for these tubes are about as follows:

The tubes must be free from surface defects, generally, and of uniform gauge all around.

The material must be of such a grade that a tube will stand being flattened by hammering until the sides are brought parallel with a curve on the outsides at the ends, not greater in diameter than twice the thickness of metal in the tube, without showing cracks or flaws.



A THREE-FURNACE SCOTCH BOILER, 13 FEET 9 INCHES DIAMETER.

A piece of tube one inch long will also be required to stand crushing in the direction of its axis, under a hammer until shortened to one-half inch, without showing cracks or flaws.

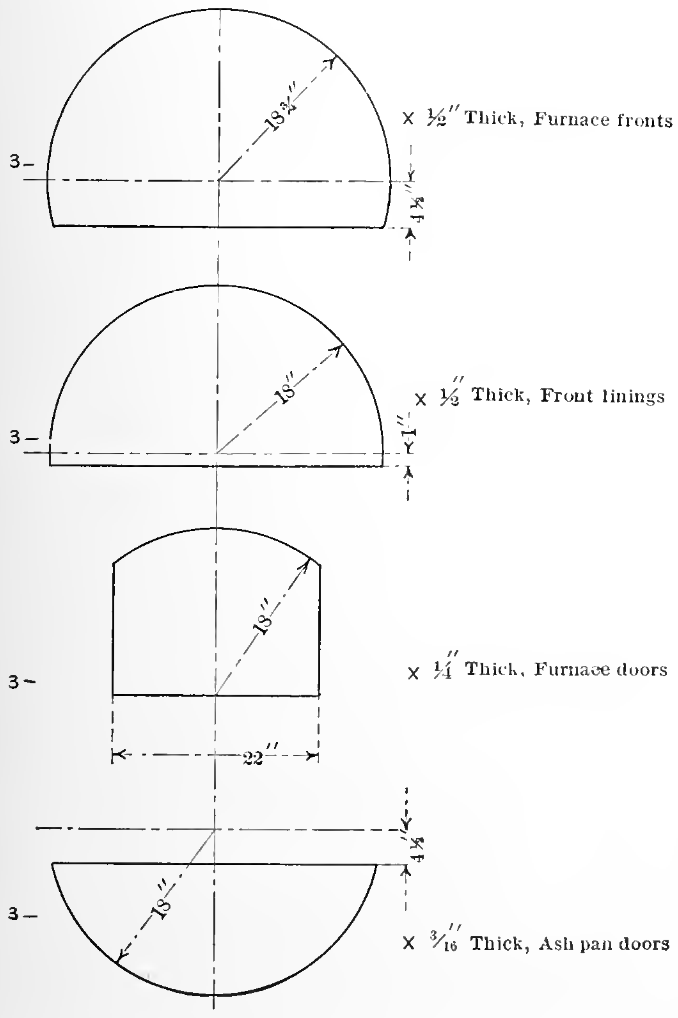
The material will be such, that a smooth taper pin (taper one and one-half inch to one foot) can be driven into it until the tube stretches one and one-eighth times its original diameter without showing signs of cracks or flaws. This test to be on a cold tube.

A tube heated to a cherry-red in daylight must stand, without showing cracks, having a smooth taper pin (taper one and one-half inches to one foot, the pin to be heated to dull-red heat) driven into it, until it stretches to one and one-quarter times its original diameter.

As the furnace fronts, doors and front linings are to be of wrought steel, we will prepare the order for this material, so that it will be delivered with the other plates.

It is not customary to specify any test for such material. The furnace fronts are secured to the ends of the furnaces by tee-headed bolts, riveted to the furnaces. A sketch, showing this arrangement in detail, will be given later, the idea at this time being to get the order for materials off with the other orders.

Plate order for furnace fronts, doors, etc.:



The small fittings, such as door-hinges, catches, latches, stiffeners and lazy bars we will make from stock in the boiler shop, as they are usually made up in this way.

The next chapter will be devoted to the laying out of the plates, after they have been delivered at the boiler shop; also to the planing, flanging and drilling of same.

CHAPTER II.

In the last chapter we made up the list of material required for the construction of the boiler.

In this issue we will assume that all the material has been delivered at the boiler shops, and will take up the work in order, arranging for the laying out, flanging, drilling, riveting, etc.

We will take for granted that all the material has been inspected and tested, and that it passed all the requirements, therefore work can be started on it as soon as received at the shop.

SHELL PLATES.

The first work to take up will be to lay off the shell plates; there being two plates forming the shell, secured together at the butts or longitudinal seams by double butt straps, treble riveted.

These plates will be taken up now and laid off for planing and drilling—thus:

The two plates are laid off first to the exact size to which they are to be planed, lines drawn and marked with center punch marks, as the lines are rubbed off in handling the plates, and with the center punch marks there the lines can be readily located when the plates are placed on the planer for planing.

The edges marked "back and front end" are planed to a slight bevel for a calking edge between heads and shell. Next the rivet holes are laid on these edges; the edges for the butts have a few holes marked off, the number being left to the boiler maker, as these are only used for tack bolts to secure the butt straps and shell together for drilling. The tack bolt holes are laid off so they will come in a rivet hole in the joint.

One piece of shell is to have a manhole through it, and rivet holes for rivets in securing the manhole stiffening plate. The opening for manhole is laid off to be drilled out; the holes are laid off so as to have a space between each hole, which is caped through to form the shell. After the butts are riveted this piece is removed by caping the metal left between each hole; the edge is then chipped fair and usually arranged for a calking edge.

After the plates are all layed off, the center of each hole is marked with a center punch; the plates are then taken to the drill and the holes are drilled through the plates.

In laying off the riveting, care should be taken in dividing up the space; the length of the seam should be figured first, and then divided up so as to make the pitch of rivets work out right. In drilling the rivet holes care should be taken to see that the drill follows through the plate straight and does not work off to one side as it goes through. After the plates are drilled, all burrs are removed before rolling is commenced.

All the holes for machine-driven rivets are drilled parallel (with a slight counterbore just a little more than sufficient to remove the burr). The holes for the hand-driven rivets are counterbored to a depth usually about three quarters through the plate. In the shell all the rivets securing it to the front head will be drilled for hand driven rivets.

Now we will suppose the shell plates are drilled; they are next sent to the rolls and rolled to the proper radius to form

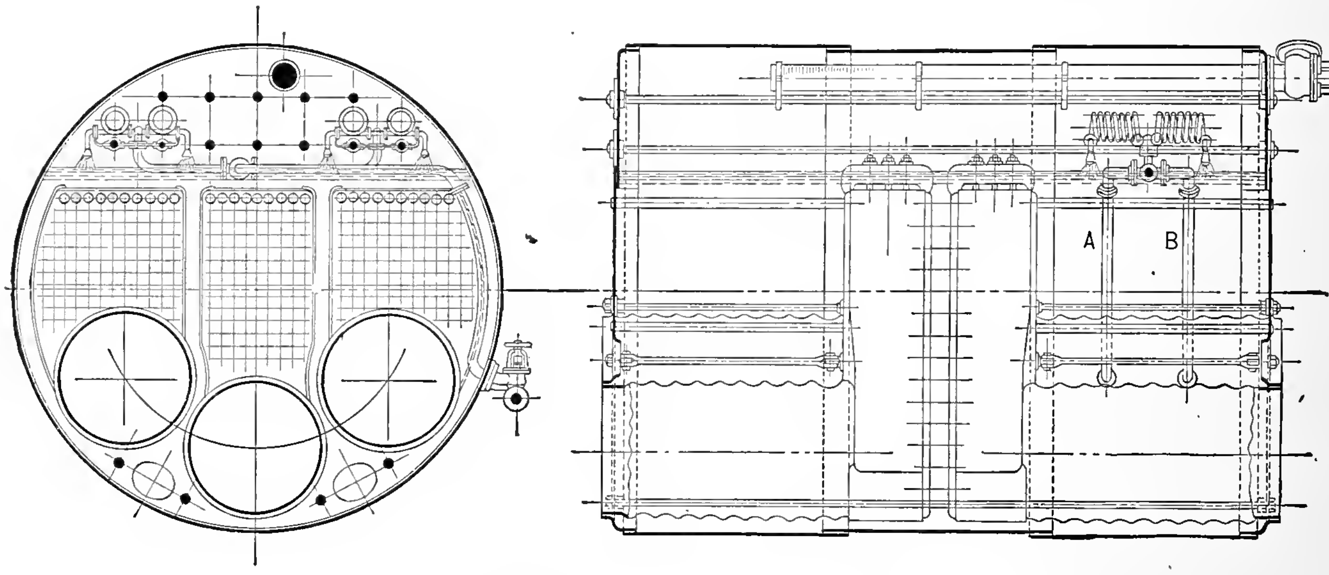
the shell, usually a template being made to which the plates are rolled. The outside butt straps are now laid off, marking the edges for planing and the center of rivet holes therein.

The straps are shaped to fit the shell plates, edges planed, and rivet holes drilled, the ends of inside butt straps are scraped down to a feather edge to go under the lap of shell and heads, the end to extend into the lap just past the first row of rivets and tack bolt holes laid off to suit those in shell plates. After this is done the two shell plates are put on end and secured with bolts passing through the butt straps and the tack bolt holes in shell and the bolts set up tight. The shell plates and inside butt straps are then drilled in place through the outside butt straps, care being taken to see that the straps are properly fitted before drilling. The piece of plate in the manhole is now removed, the edge being chipped for a calking edge.

The manhole stiffening plate is then laid off, shaped, flanged and edges planed; it is then annealed, after which it is put in place (after facing for manhole plate) and a few holes fitted. To do the work as shown here the plates would have clips bolted to them, so as to locate a center pin for them to swing on (as the flanging is on a radius) a proper height and shaped form fitted to the flanging machine, the plate fitted properly so that it will swing around the cast-iron form; after this everything is ready for heating. The plate is heated along the edge to be flanged (about three feet in length) and located on the form so as to swing properly under the flanging machine, the outside ram is lowered on the plate to hold it in position, the second ram is then lowered and turns the flange, and the horizontal one squares it up so that the flange is square and true to form.

The plate is moved around on the center pin as the flanging is done.

The holes in the front head for securing furnaces are usually drilled out, the edge chipped and the flange made by forcing a large punch through the head, a dye being under the plate. The punch is secured to the two vertical plungers of the flanging machine. The man and hand holes are put in the



A THREE-FURNACE DOUBLE-ENDED BOILER.

marked off and drilled for tack bolts. This plate is then bolted to the shell plate and drilled in place from the holes in shell, it is then machine-riveted and calked, the back head of boiler will be machine riveted to the shell, the front head will be hand-riveted to shell.

FRONT AND BACK HEADS.

Now that the shell is all riveted up ready to receive the other parts, we will next take up the heads. The laying off will be as shown by sketch.

The plates forming the heads are laid off first, showing the flanging circle and the amount to be planed from edges for joint across heads. The next thing for back head is to lay off the centers for screw stays, braces and stiffeners, rivet holes for washers of through braces and seams.

The front head will be the centers of tubes, furnaces, man and manhole plates, stays, stiffeners and rivets.

The flanging is usually done by machinery; the work as shown here is done with a hydraulic flanging machine. This machine has three plungers or rams, two vertical and one horizontal.

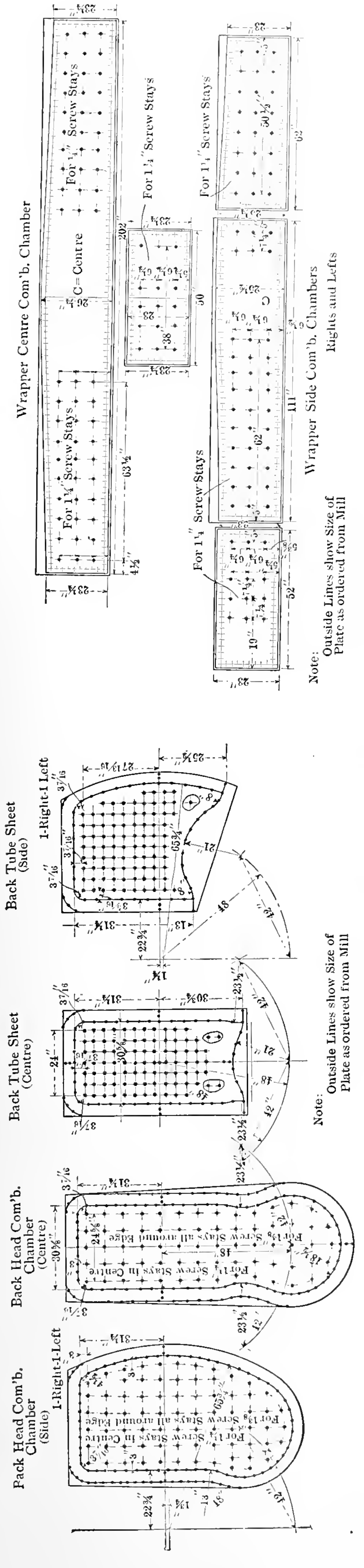
They are arranged so that different shaped heads can be same as stated above for the furnaces. The corners of all flange plates are usually finished by hand, as the metal can be gathered in or upset much better.

All edges are planed after the flanging is done. Only one sketch showing the top of head is necessary, as they are both alike.

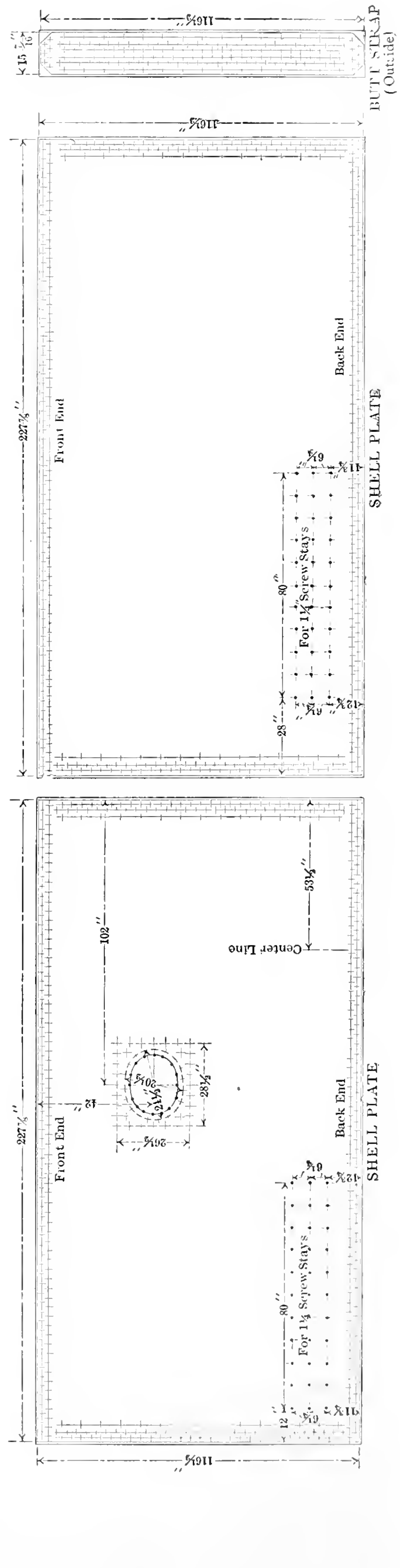
TUBE SHEETS.

The tube sheets will be next in order.

The tube sheets are laid off as shown in the sketches; the outside marks are the flanging marks; the lower ends are for joints to furnaces; the centers for holes for tubes and braces are also marked. In this case the rivet holes for securing furnaces to tube sheets are first drilled in furnace flange, and the tube sheets fitted to them and drilled through in place. The holes for tubes are first drilled with a three-quarter or one inch drill; this hole is used for a center to steady the cutter used in cutting the proper diameter out of plate for tube. This cutter is made from a flat bar, the lower end made to suit the hole drilled in plate (or rather the hole made to suit the cutter) and a cutter extending out far enough to make the proper diameter for tube; sometimes there is a cutter on each



LAYOUT OF COMBUSTION CHAMBERS AND TUBE SHEETS.



LAYOUT OF SHELL PLATES

side, that is, two cutters on one bar (one opposite the other). The upper end of this bar is made to suit the chuck in drill-press. The cutter is lowered into a hole to steady it, and as the feed is put on, the cutter goes through the plate, taking out the metal in the shape of a washer. The tube holes are chambered or counterbored on the outside where the tubes are headed over. The stay-tube holes in this case are threaded; to have the thread continuous in the two plates (back and front), they will have to be tapped in place.

BACK HEADS OF COMBUSTION CHAMBERS.

The back heads of combustion chambers will be taken up next.

They are laid out as shown, showing where they are to be flanged, and a cross and center punch mark to show where they are to be drilled for screw stays to pass through.

The edges are all chipped after the flanging is done. As this finishes up all the flanging we will take up the annealing. After the plates are flanged they are placed in a furnace and heated all over uniformly, as in local heating and flanging, there are stresses and strains set up at different places in the plates, and in heating the entire plate the metal becomes soft and the strains are reduced and adjusted to a great extent. The plate is then removed from the furnace and is straightened and shaped up, then allowed to cool off gradually and uniformly. The plates should not be worked in the fire again after the annealing. All the work should be done before the annealing, that is, the scraping, flanging, in fact all work that has to be done at the fire.

In cases with plates like the lower front head, where there is so much flanging, it is usually flanged around the edge for the shell and the manholes and handholes flanged, then the plate is taken back and annealed. After it is annealed it is brought back again and the flanges for the furnaces turned; then it is reannealed. In a plate like this the strains set up are enough to crack the plate at times and the risk is not usually taken, without annealing twice, as stated above.

The two pieces of back head are now put together and adjusted to their proper places, and the holes for rivets in seam across head drilled, the plates being held together by tack bolts.

All the edges being planed and chipped for caulking edges, the burrs are removed from each side of the holes, just a slight counterbore.

The plate is drilled for all stays (care being taken to get the right size drill for the screw stay-holes, as these have to be reamed and tapped in place). The two pieces of heads are next riveted together by machine-driven rivets; the stiffeners and washer rivets are driven in the same way. The back head is now ready to fit into the shell, locating it in the proper place with a few tack bolts. The holes in head (for joint of head to shell) are drilled through the holes in shell, thus making fair holes for all rivets. This head is usually fitted in place first, machine-riveted to the shell, this being found by experience to be the better way.

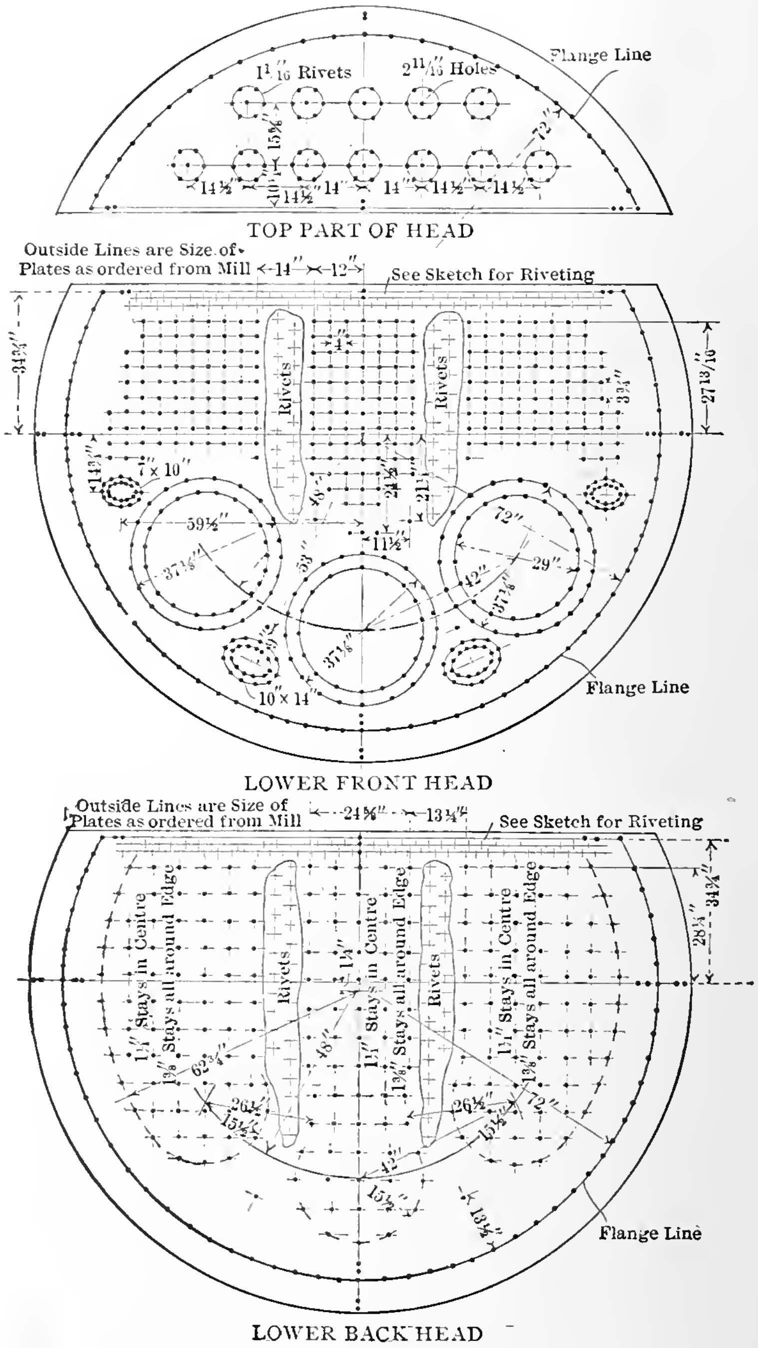
The front head is fitted in the same way, secured into the shell and the rivet holes in head drilled through the shell to make fair holes. After this is done the head is removed to allow the combustion chambers, furnaces, etc., to be fitted in place.

WRAPPER PLATES.

The next to lay out are the wrapper plates for the combustion chambers.

The plates for the center combustion chamber wrapper are shown by sketches below.

These plates are laid out, edges planed and corners scraped at laps, drilled for rivets and screw stays and shaped in rolls



LAYOUT OF FRONT AND BACK HEADS.

to suit the shape of the box to which they are connected; they are fitted in place and secured with tack bolts, and the flange plates are drilled through the holes in the wrapper plates. All the riveting in the combustion chambers should be arranged for countersunk rivets, that is, to have about one-half of the length of head of rivet countersunk, and the other half the cone-shaped head. This gives a better chance to caulk when necessary, and there is something to hold the plates together if the heads burn off.

The next are the wrapper plates for the wing combustion chambers (wing boxes).

These plates are shaped and fitted in the same manner as explained above for the wrapper plates for center combustion box. The manhole plate stiffeners, the crown bars, washers, etc., are minor details and will not be taken up, as they are shown clear and in full on the drawing of boiler.

When the back connections are all riveted and caulked, the furnaces fitted and riveted, they are fitted into the shell and blocked to their proper position, the front head fitted in place and riveted up. The rivet holes in flange of front head for furnaces are drilled in place through the holes in furnace.

The length of screw stays is next taken and the screw stays made and screwed into place. The metal is calked around each stay on both sides, that is, on the outside of shell and on the inside of combustion chamber plate. After the plate is caulked around the stays, nuts (and washers if necessary) are fitted and set up tight.

The braces, crown bars and tubes are next fitted. The next chapter will take up furnace fronts, bearers, bridge walls, grate bars, uptakes, etc.

FURNACE FITTINGS, ETC.

The fronts are usually made of wrought steel plates, secured to the furnaces by studs (special) riveted to furnace, as shown in Fig. 14.

The fronts thus secured, the front bearer bar, or dead plate, is secured to them. The door frames are of cast iron, forming a distance piece between the front plate and the lining, and are made in three pieces for convenience in making repairs, the center piece being the width of the fire-door opening; this is 4½ inches deep. The lining is of wrought steel plate, bolted through the frame and front, the heads of bolts being placed inside and the nuts outside, as the nuts should be kept away from the fire. If the nuts were placed inside it would be difficult to remove them for repairs, due to the threads being burned. The fronts and linings are each in one piece, the frame in three pieces.

The doors are of wrought steel, 3-16 inch thick, flanged and drilled for air holes, slice bar door, sagging bolt from upper hinge and latch for holding door open when firing the furnace. The door is fitted with a cast iron lining, the lining having sockets cast on it, through which the bolts pass; the heads of bolts are recessed into lining to keep them out of the fire as much as possible.

The arrangement of door is shown in detail on drawing. The front bearer is of cast iron and shaped as shown; it is secured to the furnace front and frame, and is beveled to receive the grate bars.

The grate bars are in two lengths, supported by two bearer bars in center; these bearer bars are supported by two half round bars, made to fit in the corrugations, so that they will not extend above them and interfere with the ash pan. The upper ends are bent in and tied together by wrought steel plates; these plates are notched to receive the bearer bars, which are 3 inches by ¾ inch, and let into the side plates so as to support the ends of grate bars at the center of the furnace.

The back bearer is formed by one casting, supported by

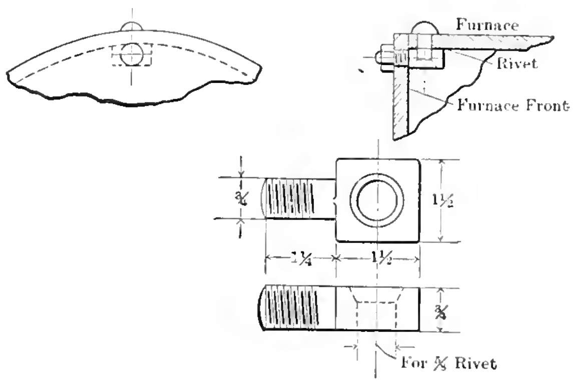


FIG. 14.

half-round saddles in the same manner as the middle bearers, except that the supports are secured to the bearer direct, flanges being cast on bearer for that purpose.

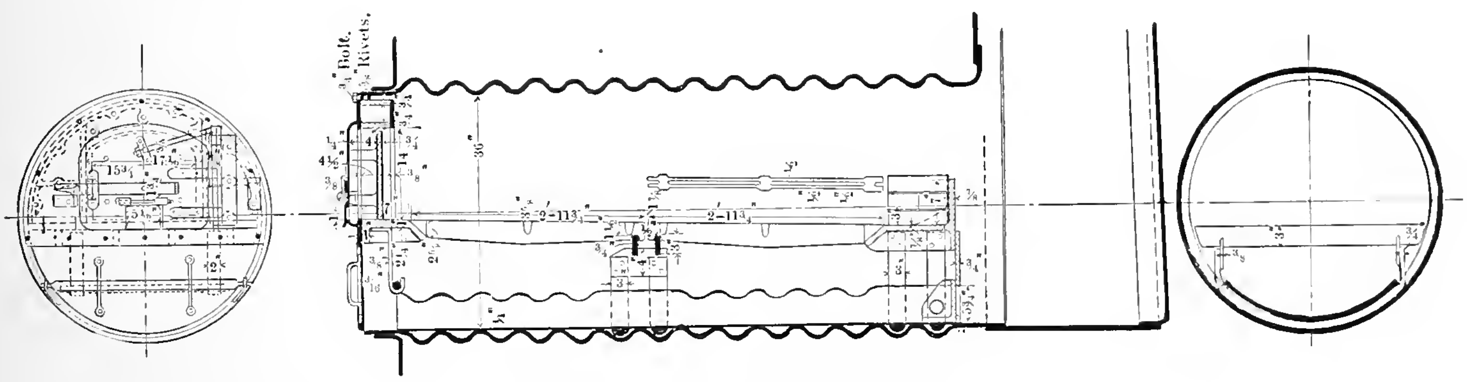
This casting is shaped so that a shelf is provided for the bricks to rest on in building the bridge wall.

The bridge wall is built up of brick and fireclay, the top being crowned, allowing a clear opening over it of about 16 per cent. of the grate surface. With this area over bridge wall there will be no trouble and the boiler will steam well.

With this arrangement of furnace fittings it will be noticed that there are no fastenings into the plates or into steam or water space, and, therefore, no chance for leaks around fastenings.

Sometimes a plate is fitted to extend from the back end of bridge wall to the back plate of combustion chamber on a line with the grate bars. This plate is then covered with firebrick. If a plate is fitted in this way, care should be taken to give clearance all around the edge of same, to allow it to expand when fires are started.

Oftentimes a firebrick lining is built upon this base to ex-



ARRANGEMENT OF FURNACE FITTINGS.

tend up the back head of combustion chamber to a height just above the top of furnaces, so that the flame does not strike direct on the plate as it passes over the bridge wall.

The brick lining fitted in this way should be the depth of the screw-stay nuts away from the plate, leaving an air space between the bricks and plate.

The arrangement as shown here is with a vertical plate from the bridge wall down to bottom of furnace. With this arrangement it is customary to fit a door in the plate at its lower edge, so that the soot can be hauled out of the back connection into the ash pan with a hoe; the door must be made to be handled from the fire room.

With this arrangement, as one will see, a much larger combustion chamber, or a larger volume, is maintained, which will result in a decided increase in the efficiency of the boiler for making steam.

To form a smooth bottom for ash pan a ¼-inch plate is rolled to fit the bottom of furnace on top of the corrugations; the top edges of this plate are shaped to fit the corrugations on each side, as shown. This plate will extend the entire length of the furnace, and can be readily removed. Sometimes with this style of bridge wall and plate, bricks are built up in the combustion chamber back of the vertical plate from the bottom of furnace to top of bridge wall; in this way the flame does not touch the metal. This brick wall is very advantageous, especially if the boilers are to be forced. The ash-pan doors are of 3-16-inch sheet steel, shaped as shown; theyare stiffened up with ¾-inch half-round bars, riveted all around the edge. They are fitted with trunions and handles, and are often fitted with cleats on the back for hanging up when not in place on the furnaces. If they are thrown around the fire room floor they soon get out of shape, therefore should be hung up when not in use.

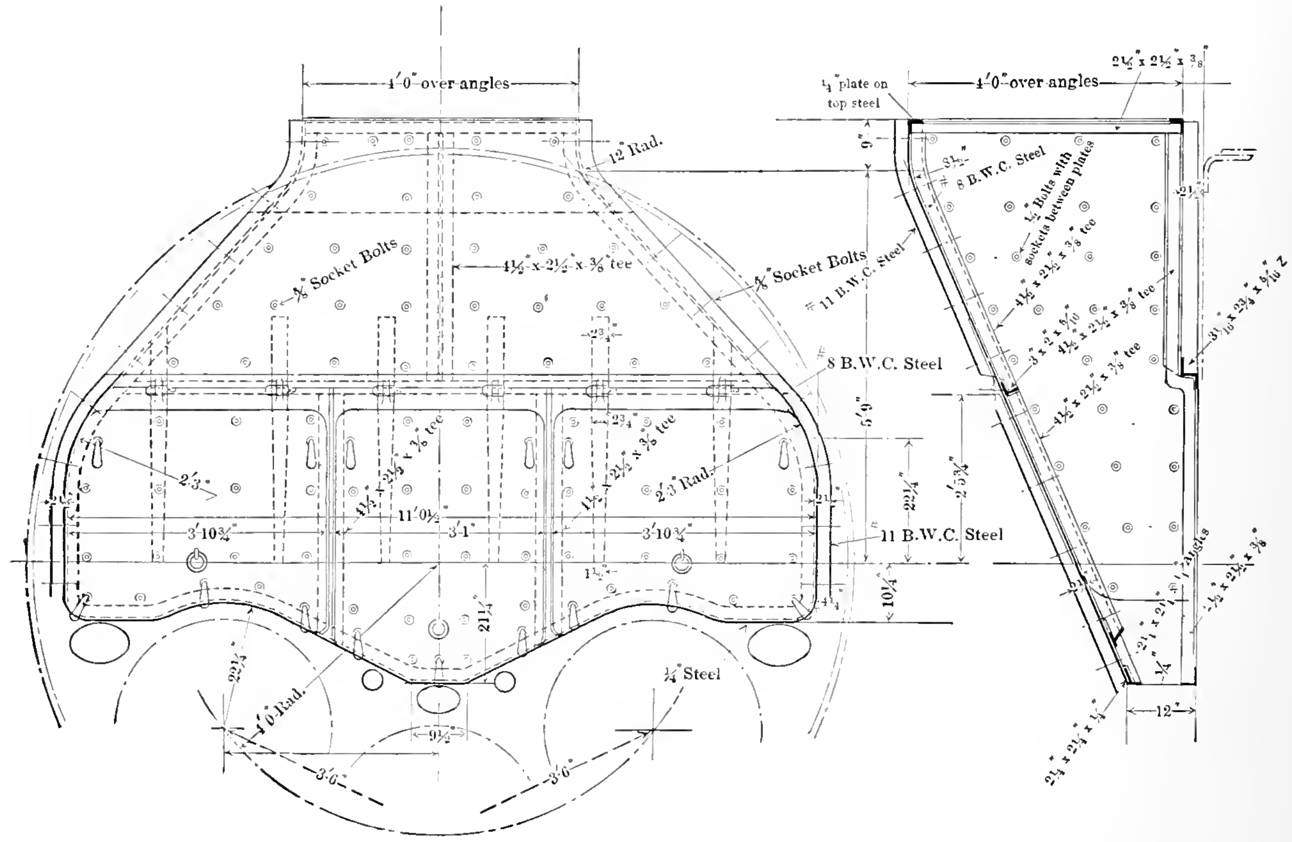
Two wrought iron bars, 2 inches by ⅜ inch, are shaped up and secured to the front bearer, or dead plate, to support a lazy bar, the bar to be 1¼ inches diameter, as shown on the drawing.

The grate bars are in two lengths, 3⅝ inches deep at middle and 2⅝ inches deep at ends; they are ½ inch thick at top with ½ inch air space, and are ¼ inch thick at bottom in the middle.

The side bars are made to suit the corrugations. The bars are made double, although it is customary to carry some single bars.

UPTAKES.

Taking up the subject of uptakes, we have arranged for an inner smoke pipe of 43 inches diameter, and an outer pipe, or casing, of 52 inches diameter, giving an air space of 4½ inches between the two pipes.



ARRANGEMENT OF UPTAKES.

The uptake is made square on top, a square plate riveted to an angle-bar frame, the angle on the smoke pipe is on the outside, and will secure through the plate and angle at four points and the plate only between these points. This makes very easy construction for securing the pipe and also for making the top of uptake.

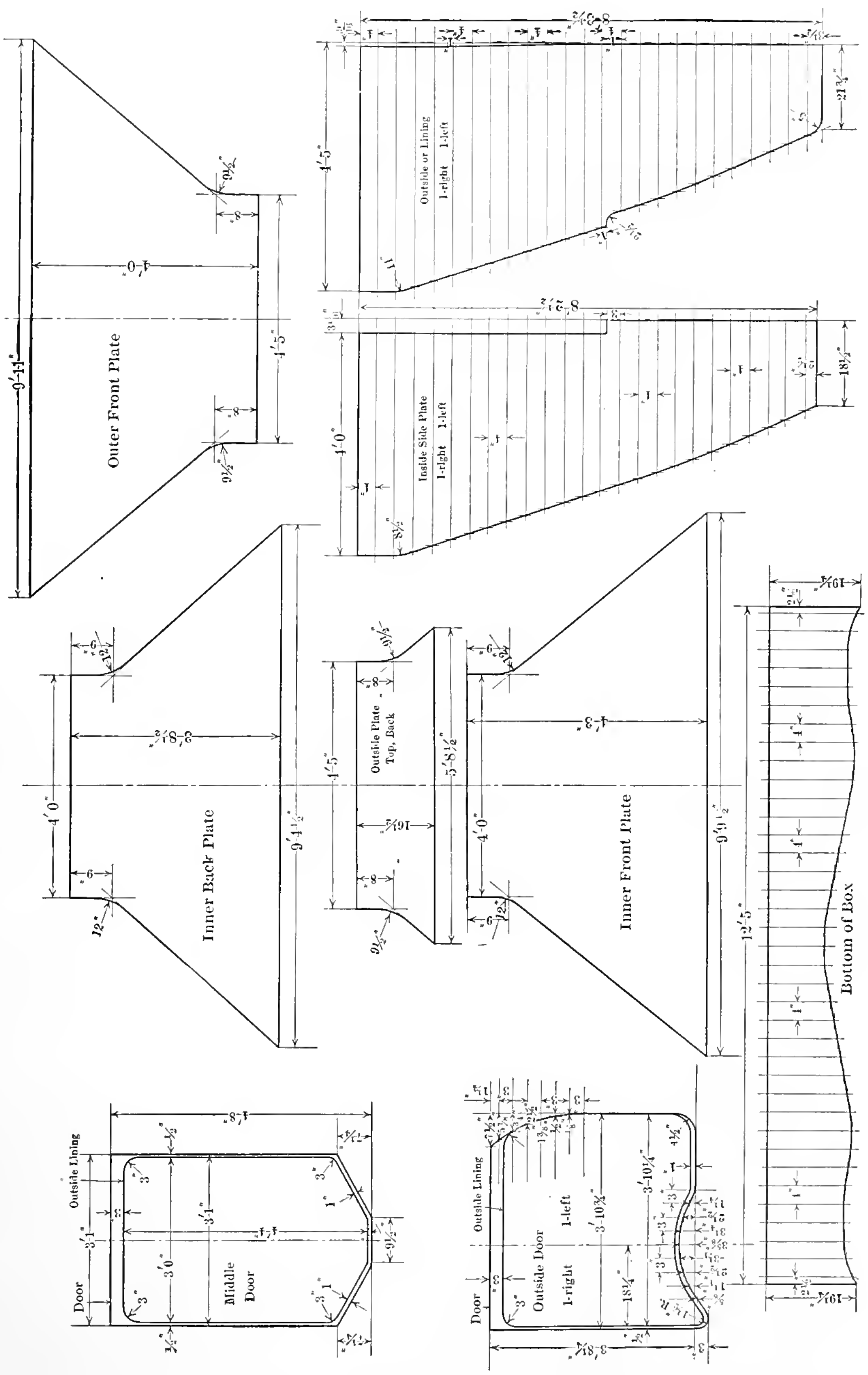
The margin angle secured to the front of boiler for uptake is a 2½-inch by 2½-inch by ⅜-inch angle in two lengths, the joint being at center on bottom of uptake. This angle is offset to suit the Z-bars and then extends up parallel with the head of boiler to top of uptake. The Z-bar is secured to the front head of boiler, as shown on drawing.

In arranging the uptake the flame does not strike the front head at steam space or the nuts for through braces. After the angles and Z-bar are secured to the boiler the bottom plate of uptake is then secured in place; this usually has the margin angles secured to it; these angles are 2¼ inches by 2¼ inches

by ¼ inch in two lengths, the top ends being held in place by braces until the plates are secured. The bottom plate of uptake is made of ¼-inch steel plate. The top plate is made of the same thickness and material, all the other plates of the box proper are made of No. 8 B. W. G. steel.

inches by 5-16 inch, is fitted from side to side; this angle also makes a landing for the upper edge of doors.

To form a landing for the inboard edge of the outside door and the sides of the middle door, T-bars are fitted 4½ inches by 2½ inches by ⅜ inch, secured to the 3-inch by 2-inch by



LAYOUT OF UPTAKES.

The outside lining, or casing, is made of sheet iron or steel, No. 11 B. W. G. in thickness; the casing, or lining, is set off from the box proper 2½ inches, bolts and sockets being used, with heads on the inside; the spacing of these bolts is shown on the drawing. These bolts are ⅝ inch in diameter.

To stiffen the front of uptake an angle-bar, 3 inches by 2 5-16 inch angle-bar and extending down and secured to the 2¼-inch by 2¼-inch by ¼-inch angle-bar at bottom; they are offset at each angle, so as to be flush with the other angles, to form a good face for the door to close tight.

Two T-bar stiffeners are fitted to upper part of uptake, one at front from the 3-inch by 2-inch by 5-16-inch angle to top of uptake, and one at back from Z-bar to top of uptake.

The doors are fitted with long strap hinges, which are also used as stiffeners, Fig. 15. Each door is fitted with five lever catches for securing it in place; catches made as shown in Fig. 16.

Each door is also fitted with a ring bolt for holding the door up when working in smoke-box. The ring bolt is fitted through both plates, with a nut on the inside and a socket between the plates.

Sometimes the air space around uptake, as shown here, is filled with carbonate of magnesia, asbestos, or other non-conducting material; where this space is to be filled in, the openings at edge and ends are arranged to be closed so that the non-conducting material cannot drop out.

Another style is to have a space of about 2 inches filled in with a non-conducting material, and 2 or 3 inches outside of this to have another casing or lining; in this arrangement there are three sets of plates, or three separate casings for the uptakes. This makes a first-class uptake, and adds materially to the comfort of those in the fire room, making it cooler, which means much in some cases. It adds considerable to the cost, as an uptake with three casings is very much more expensive to construct.

Dampers are sometimes fitted in uptakes, but usually for one boiler it is customary to fit a damper in the stack above the uptake.

Now, as to laying off the plates for the uptake. The top plate will be 48 inches square, with a 43-inch hole in it, so we will not bother with making a sketch of this plate.

The side plates of outside casing will be made in one plate for each side, from top of uptake to bottom, as shown on front view of uptake drawing.

First, we will start and step off any number of spaces, say 4 inches apart in this case, starting at the top (front view) and step all the way down to the bottom of plate, as in this view we can get the full length of plate; after we have stepped off all the spaces we project them over to the side view. Now we extend a line up to top of uptake, just fair with the outside

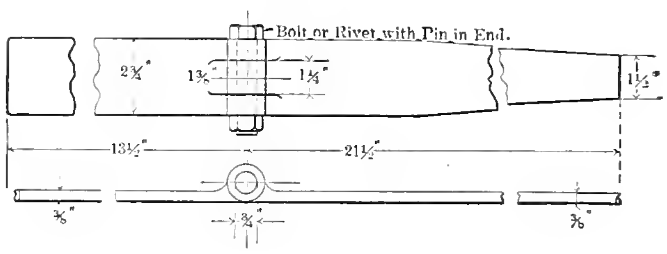


FIG. 15.

of lower part of front head. After this is done take a stick long enough to reach the longest measurement, start at the top of box and mark off all the lengths on lines projected over from front view. After all these lengths have been marked off on the stick, two lines are laid off on the plate (as A. B. C. on sketch); lay the stick on each line (the lines having been laid off on plate 4 inches apart) and mark the exact length on each line; after this has been done bend a batten through all the points and draw the line; this gives the line to which the plate is to be sheared. The holes for socket bolts and rivets are next laid off. After all marks are fixed with center-punch marks, the plate is sheared to size and holes punched. It is then shaped to the work or angles of uptake.

Sometimes the rivet holes are not put in until the plate is shaped and clamped in place and holes marked off from angles. This finishes the outside sheets at side, one right and one left; they are both laid out from one template, the right and left being made by the bending or shaping.

The side sheets for the inner casing are laid out in exactly the same way, but these will have to join the bottom plate, so

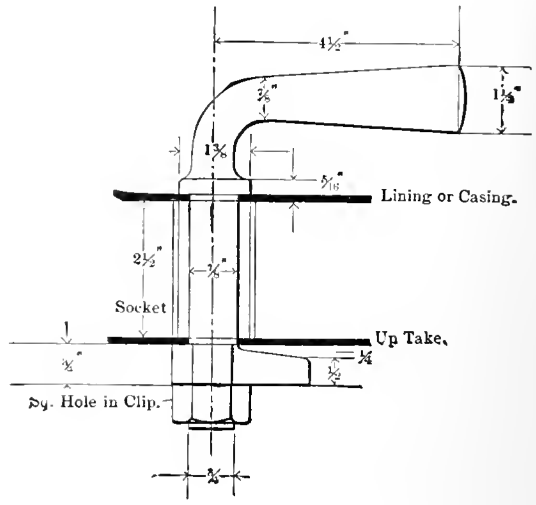


FIG. 16.

as to close the space entirely; the joint, or seam, is just above the radius at lower corners. These plates are rights and lefts after they are bent the same as the outside plates.

The outside front plate at top is measured off on the side view to get the true length; the widths are taken from the front view and the spots joined, forming a radius at top with side lines.

The inside top plate front is laid off just the same as the outside plate; this laps the angle at top of uptake and extends down to the 3-inch by 2-inch by 5-16-inch angle across the front of box; it laps 1¼ inches on this angle, leaving ¾ inch lap for the door plate to rest on.

The back plate and lining can be taken from the front view, as the exact shape of each is shown there.

The bottom plate, or bottom of uptake, will be taken up next. First, start at center of box, on bottom (front view), step off any number spaces all the way around to the joint at corner. In this case we have taken 4-inch spaces. We need only lay out one-half of this plate, as both sides are the same; after one-half is laid out we can use it as a pattern for the other side. After spacing the 4-inch distances they are projected to the side view, and the distance from the face of boiler out to each spot will be the length or width of plate at that point. Now, get these distances on a stick or batten, lay off the 4-inch spaces on the plate, and from one square edge mark off the neat length on each line taken from the stick; after all the spots are marked on the plate a batten is bent around and a line drawn through all the spots. This will give the shape the plate is to be sheared to.

The doors and door linings are next. The exact lengths are taken from the side views. The shape of the bottom edge is given by setting off spaces on the front view and projecting them over to the side view, and measuring up on the slant

height from those spots. The door lining and casing above hinges are left open, or a space given so that they will not foul when the doors are swung open. The lever catches for securing the doors in place are made to pass through both casings, and secured by clamping angles and T-bars, as shown.

BOILER MOUNTINGS.

The designing of a Scotch boiler is thoroughly understood by most engineers, although at times the arrangement, location and manner of securing the fittings to the best advantage are lost sight of, and after the boiler is placed in the vessel some of the valves are in positions that are inaccessible, and for this reason are not properly looked after.

The greatest amount of thought and care should be taken with each valve to locate it where it can be readily reached, and so that it can be properly overhauled and repaired when necessary.

The valves that are generally lost sight of and placed in inaccessible places are the surface and bottom blow valves and the drain valve or cock. These valves are generally placed on the shell, the bottom blow valve somewhere on the bottom of boiler; this space is necessarily cramped, as there is usually very little space between the bottom of boiler and bottom of vessel or the coal bunker bulkhead. Taking, for example, a vessel with only one boiler. The bunker bulkheads are usually located as near the boiler as possible to gain the greatest amount of coal capacity. There is also located in this space the boiler saddles, and in most cases braces for securing the boiler from displacement in a fore and aft direction, and the ash guards in front of the boiler to keep the ashes out of the bilge, so that by the time all these are located there is very little space left, and in some cases there is not enough room for a man to get in to operate these valves and they are fitted with extension stems or handles so they can be operated from the fire room. The space over the boiler is usually covered with some sort of a deck in the deck house to utilize all the space available; if the space does not permit of headroom it is turned into locker room.

The boiler is almost completely covered in, and in some cases there is only enough of the boiler extending from under this deck upon which to get the steam connections. The surface blow valve is usually located under this deck, in a very inaccessible position. With this kind of an installation the boiler is very hard to take care of and in many cases is almost inaccessible. Repairs are necessary on all boilers, and bills for such are just as certain as the boiler is to generate steam, and when the repairs are necessary the extra time necessitated by working in cramped places means extra expense; very often the space is too cramped to make a thoroughly good job and a temporary job is made, which has to be remade over and over again. In installing a boiler in a vessel it is well to give sufficient room to get at all parts of the boiler so that it can be taken care of regularly, and in doing this the repair bills are cut down to a minimum.

The main steam-stop valve, the safety valve and the auxiliary steam-stop valve should be located on one nozzle, branches being made on the nozzle for each; with this arrangement only one hole in the shell is necessary, thus saving time and expense in fitting extra flanges to the curved surface of the shell, as these have to be chipped, scraped and fitted by hand, whereas if they are secured to the casting, all the flanges are faced by machine, thus taking much less time in fitting up and making the joints. In using the nozzle another advantage is that the shell is not weakened by cutting several holes through it unnecessarily.

The dry pipe is usually a copper pipe (generally tinned inside and outside), secured in the highest part of the steam space; the top of the pipe is perforated with small holes or has saw-slots across it; the combined area through these holes or slots should be the same as the area through the casting—that is, equivalent to the area of main auxiliary steam pipe. If the outlet is on the shell it can be located anywhere in a fore and aft direction, according to the available space, although not too near to the end of the shell plate as the tendency is to weaken the plate by being too near the edge.

The branch on the dry pipe has a flange secured to it of about the same diameter as the flange on the nozzle; this flange sometimes has a spigot end on it to pass through the shell plate and just enter the nozzle, in this way covering the two joints and also the shell plate in the steam passage. The ends of the dry pipe are closed with solid discs and the pipe is secured to the shell with steel bands or straps shaped to the pipe and secured to the shell by tap bolts (the holes for bolts not to be drilled through the plate), sometimes a small hole is drilled in the bottom of pipe at the lowest point, to be used as a drain. The flange of nozzle is chipped and scraped to the shell so that a good bearing is made, and it is generally bolted in place, the bolts passing through the flange, the shell and the flange on branch of dry pipe, the nuts of bolts to be placed on the outside.

The nozzle is sometimes riveted on and calked on the inside if it is made of cast iron; if it is made of steel and riveted on, it is calked on both sides. If the nozzle is riveted on, the dry pipe is secured separately with tap-bolts, spaced inside of the line of rivets.

The stop valve should be placed on the nozzle so that the pressure is under the valve, and, if possible, there should be a by-pass valve fitted where the stop valves are of large diameter, this valve to be used when first turning steam in the main steam pipe for warming up before getting under way, thus reducing the chances of having the main stop valve opened too suddenly when first turning steam to the engines.

The safety valve should be in a vertical position, and if the area is large a more satisfactory job can be had by using two smaller valves mounted on one base, having one inlet and one outlet.

With this arrangement the valves and springs are small and give less trouble, the combined area through the two valves must be the same as the one large one.

In securing these valves through bolts should be used wherever possible, as studs give much more trouble than through bolts.

If a stud breaks off in setting up on the joint, the broken

piece has to be drilled out and probably no studs of the size will be found on board, or will there be time to drill it out, as such things usually happen when there is little time for making repairs.

The whistle valve should be secured direct to the boiler and not to any other pipe. It should not be connected to the dry pipe, as it is a small pipe and will work satisfactory from the boiler direct. It will work unsatisfactory if taken from one of the branches of the auxiliary steam pipe, as there seems to be water pocketed somewhere, and every time the whistle is opened this water is picked up and blown out through the whistle, thereby delaying the time the whistle should sound until all the water is blown out through it.

The surface blow valve should be located in some convenient place on the shell.

In reference to the manner of securing this valve there is a difference of opinion among engineers as to having it secured with the pressure under or on top of the valve; if secured with the pressure on top of the valve and the valve or disc is guided with wing guides, it would seat in the case of the stem breaking, which is an advantage, and about the only advantage that can be claimed for securing it in such a manner. The valve usually has an internal pipe fitted to it, extending to about the middle or center of the water surface; the inboard end is fitted with a scum pan, which is a shallow funnel-shaped disc, made of plate steel, from 12 to 16 inches in diameter; the pipe is connected somewhere at the bottom according to the space available; the top of the pan is usually located about 4 inches above the top of the boiler tubes; the outboard end of pipe is expanded into the opening in shell (although some times it has a flange on it and is held in place by the same bolts that secure the valve); the valve flange has a spigot end on it which enters into the pipe where it is expanded into the shell, and the flange secured to the shell by through bolts, the nuts being on the outside.

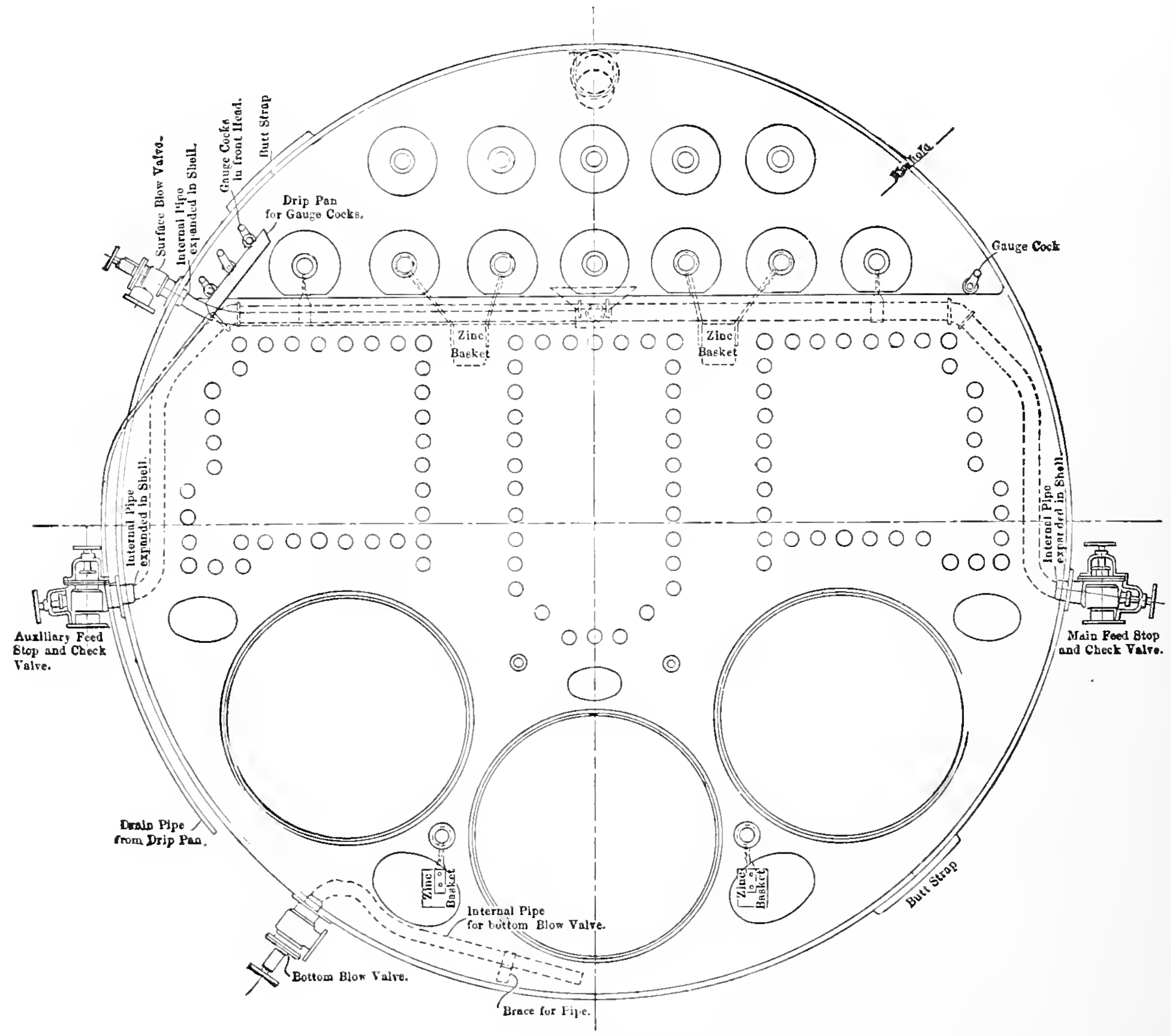


FIG. I.—END ELEVATION.

The bottom blow valve is secured in the same manner as the surface blow valve, its internal pipe leading to the bottom of the boiler; this has no pan on the end, just a square end on the pipe. About the same can be said of the bottom blow valve as was said of the surface blow valve, as to the manner of securing it with reference to the pressure on top or under the valve. The internal pipes are secured by iron braces to the through stays to hold them in the proper position.

The size of bottom blow valves range from 1½ inches to 2½ inches and the surface blow valves from 1¼ inches to 2 inches, according to the size of boiler. The surface and bottom blow valves are connected together by pipes on the outside and a branch connected to a sea valve on side of vessel, or if

passing through the side of vessel, above the water line, no valve is fitted to the vessel, but a flange is usually fitted with a nozzle to direct the discharge down to the water, as to have it blowing straight out is very unsatisfactory.

The drain cock should be located at the lowest part of the boiler, if possible. This should be a flange cock with spigot end, the cock to have a permanent handle, made to point down when the cock is closed. A cock is preferable to a valve for drawing.

On account of the galvanic action set up in a boiler it is customary to place a quantity of zinc in it. The zinc is held in plate-steel boxes called baskets, the average size of these baskets is 6½ inches wide, 6½ inches deep and 12½ inches long, the sides and ends are perforated with ⅜-inch holes, the perforations extend down to about 1 inch from the bottom, the baskets have hangers riveted on for supporting them from the through braces, the hangers being clamped to them; the joints should be carefully made so as to keep a thorough metallic contact. The zinc plates average in size 6 inches wide, 12 inches long and ½ inch thick and are dropped in the basket and secured to it by a bolt passing through them with a washer placed on the bolt between each zinc (fitting the zincs properly is quite a tedious job). Thus is secured a metallic contact with all the zincs. Care should be taken not to fill the baskets too full, as the zinc expands under chemical action and will burst the basket if there is not sufficient room for it. These baskets are located in different parts of the boiler at top and bottom, generally in the water spaces. The amount of such zinc to be placed in a boiler is from 2 to 2½ pounds per square foot of grate surface.

The solid bottoms in the baskets hold the zinc from getting in the blow valve when it crumbles off and breaks up.

The gage cocks, if possible, should be located on the head of boiler, as a much better arrangement can be made for working them from the fire room, and they are more protected there than in any other place. If placed on the shell they are hard to operate and unprotected; if placed on the water column they are not direct, as they are connected to the boiler by pipes and valves.

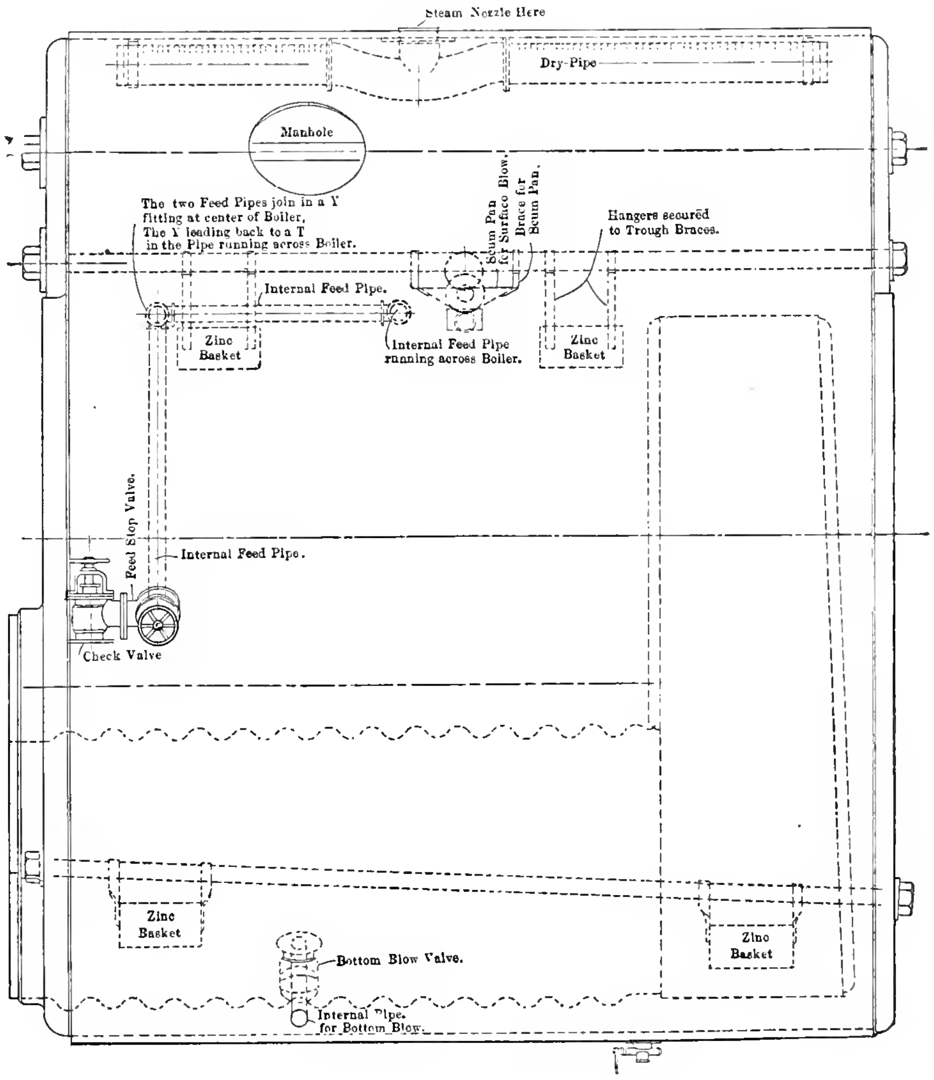


FIG. 2.—SIDE ELEVATION.

A stand-pipe is of very little use, except to hold the glass in the bearings, and is very often done away with, using a plate to keep the glass tube from pulling out of place, the pipe connections being made to the end fittings or cocks direct.

The gage glass is located in some convenient place about the center of boiler if possible; if this is impossible there should be two gages, one on each side.

The top is connected to the steam space of boiler by copper pipe and valve; care should be taken not to locate it too near other openings as it may reduce the pressure some and give the wrong reading of water in the glass. The bottom is

connected to the water space of boiler with copper pipe and valve. The automatic closing valves on the water column is a very good arrangement if properly made, as a glass tube is liable to break at any time, and when it does the automatic valve closes the opening in valve so that repairs can be made without going through escaping steam and hot water to get to the valves to shut them off.

If the gage cocks are placed in the head there should be four fitted, three on one side and one on the other side, the single one should be the same height as the lower one of the three. The lower gage cock should be about on a line with the highest heating surface and the other two placed 4 inches apart above this one. A copper drip-pan with drain pipe leading to the bilge should be fitted to the nest of three cocks and thoroughly secured in place, the single cock does not need a drip-pan, as this one is not used as often as the others, it only being used when the vessel is listed.

If the plates of the boiler are thick enough these cocks should be screwed into the plate, for if flange cocks are used the flanges require considerable space and the bolts for securing them are necessarily small and liable to give trouble. The cock properly screwed into the plate gives a more satisfactory job.

It is a good plan to have a mark on the boiler, or somewhere on the uptake, showing the water level when it is just covering the highest heating surface, with the vessel in normal trim, as this is a good thing to know at times.

The feed-pipes are double, one the main feed and the other the auxiliary feed, they should always be on opposite sides of the boiler. They are fitted to the boiler in some convenient place, either on the head or shell, but should be located so that they can be operated from the fire room floor. The internal pipes are expanded into the opening in boiler plates, the top valve flange has a spigot end, which enters the pipe where it is expanded, the stop valve is secured in place with through bolts, having nuts on the outside. The check is bolted to the stop valve in a vertical position; the check should be arranged so that the lift can be regulated.

The internal pipes sometimes are separate throughout, and sometimes they are connected together at the top and then continued as one pipe. If connected together they enter a Y-fitting at the center of boiler over the top of the tubes, and then a single pipe extends back over the tubes to a T, and from this T a pipe extends out on each side, with a cap on the outboard end; sometimes the outlets are made so as to have one point down in each water space, sometimes the pipe is perforated all along the bottom and sometimes there are a row of holes on each side of the pipe, discharging the water in a spray horizontally. Sometimes the feed is discharged all in one place, the full diameter of the pipe, but this is not good practice. If the main and auxiliary feed-pipes are connected together on top of the tubes and then continue as one pipe, there is much less room taken up and the arrangement seems to work as satisfactory as two separate pipes. These pipes are supported by iron hangers secured to the through braces, in such a manner that the pipes will not be too rigid, but will have some flexibility. There are several ways of circulating the water or warming the water in the bottom of a Scotch boiler when first getting up steam, but when there is only one boiler none of these are of much use, as the heat, which is the agent in all, is furnished from another boiler and in a case of one boiler would have to be generated by that boiler alone; it helps some, as there is always dead water in a Scotch boiler, even when steaming, as it generally causes a circulation.

In some boilers a small weighted safety valve (called a sentinel valve) is fitted; this is about ½ inch area and is set to blow at 3 or 5 pounds above the working pressure; it is another valve to look after and there is a question as to its usefulness.

Specifications for a Three-Furnace Single-Ended Scotch Boiler.

The following is a typical set of specifications for a Scotch boiler. While the figures quoted apply to a boiler which is to be installed on the United States revenue cutter No. 16, the requirements represent the best of marine boiler construction at the present time.

The Boiler.

The general dimensions of the boiler will be:

Diameter of shell (inside), 13 feet 6 inches.

Length over heads (bottom), 10 feet 3 inches.

Number of furnaces, three.

Diameter of furnaces (inside), 40 inches.

Total grate surface, 60 square feet.

Total heating surface, 1,803 square feet.

The boiler shall be designed for a working pressure of 180 pounds per square inch.

The design of this boiler will be furnished by the government. The various details will be worked out by the contractor and submitted to the Engineer in Chief, U. S. R. C. S., for his approval, before work is commenced on the construction of the same.

The boiler shell will be made in one course and will consist of two plates 1¼ inches thick.

Each head of the boiler will be made of two plates, the upper one being 15-16 inch thick and the lower one ¾ inch thick. The front head will be flanged outwardly at the furnaces and both will be flanged inwardly at the circumferences. The front head will be stiffened by angle bars and the back head by doubling plates riveted on, all as shown on the drawing.

The tube sheets will be ¾ inch thick. They must be accurately parallel, and all tube holes will be slightly rounded at the edges. The holes for the stay tubes will be tapped together in place.

The boiler tubes will be of cold-drawn seamless mild steel, the best that can be obtained on the market, and subject to the approval of the engineer in chief. All tubes will be 3 inches in external diameter. The ordinary tubes will be No. 10 U. S. S. G. in thickness and will be swelled to 3 1-16 inches external diameter at the front end. The ends will be expanded in the tube sheets and beaded over at the back end. The stay-tubes will be No. 6 U. S. S. G. in thickness and will be upset at both ends to an external diameter of 3 3-16 inches, leaving the bore of the tube uniform from end to end. They will then be swelled at the front ends to 3 7-16 inches external diameter. They will be threaded (twelve threads per inch) parallel at the combustion chamber ends and taper at the front ends to fit the threads in the front tube sheet. They will be screwed into the tube sheets to a tight joint at the front ends and will be made tight at the back ends by expanding and beading. All the expanding will be done with approved tools. All of the tubes will be spaced 4 inches from center to center vertically and 4¼ inches horizontally.

There will be a separate combustion chamber for each furnace in the boiler, as shown on the drawing; they will be made of 9-16-inch plates at top and back and 19-32-inch plates at the bottom and sides, as shown. The tube sheets will be as before specified. The tops of the combustion chambers will be braced by steel-plate girders, with the edges machined, as shown. The plates will be flanged where necessary, and all parts will be joined by single riveting. The holes for the screw stay-bolts in the plates of the combustion chambers and shells will be drilled and tapped together in place.

The bracing will be as shown on the drawing. The combustion chambers will be stayed to the shell of the boiler by screw stays 1⅜ inches in diameter over the threads, with twelve threads to the inch, screwed into both sheets and fitted with nuts, the nuts to be set up on bevel washers where the stays do not come square with the plates. The washers will be cupped on the side next to the plates and the joint will be made with a cement of red and white lead and sifted cast-iron borings. Where the nuts set up directly on the plates, they will be cupped out and the joint made with cement. The combustion chambers will be stayed to the back heads by screw stays 1½ inches in diameter over the threads around the edges of the combustion chambers and 1⅜ inches diameter over the threads elsewhere. When the nuts are up in place, the washers must bear solidly against the plates with which they are in contact. The holes for all screw stays will be tapped in both sheets together in place. All joints around stays will be calked tight under 100 pounds hot-water pressure before the nuts are put on.

The upper through braces will be 2⅜ inches in diameter, upset on the ends to 2⅝ inches in diameter, and threaded eight threads to the inch. The nuts for the upper through braces will be of wrought iron set up on washers, inside and outside. The outside washers will be about 8½ inches in diameter and 15-16 inch thick in the two upper rows, and about 7½ inches in diameter and 15-16 inch thick in the lower row. The washers will be riveted to the heads by six ¾-inch rivets. The inside washers will be cupped for cement, as shown. No packing will be used.

All screw stays will have the thread cut in a lathe, the length between the plates being turned down to the bottom of the thread, as shown on the drawing.

All braces will be of steel, "Class A," and without welds, except the two 2-inch braces on the wing combustion chambers which will be made of wrought iron, as shown on the drawing. The crowfeet on the combustion chamber will be made of wrought iron. The screw stays will be made of steel, "Class B."

The longitudinal joints of the boiler shell will be butted with 1¼-inch straps, inside and outside, and treble-riveted, as shown on the drawing. Joints of heads and joints of heads with shell will be double-riveted, as shown. Joints in furnaces and combustion chambers will be single-riveted. All rivets will be of open-hearth steel, "Class B," except for the rivets in the longitudinal joint for the shell plates, where the rivets will be of "Class A."

The edges of all plates in the cylindrical shell and of all flat plates, including the girders for the tops of the combustion chambers, where not flanged will be planed. Edges of flanges will be faired by chipping or otherwise, as approved.

Plates in cylindrical shell must not be sheared nearer the

finished edge than one-half the thickness of the plate along the circumferential seams and not nearer than one thickness along the longitudinal seam. All rivet holes will be drilled in place after the plates have been bent, rolled, or flanged to size, and fitted and bolted together; after the holes have been drilled the plates will be separated and have the burs around the holes carefully removed. Hydraulic riveting will be used wherever possible, with a pressure of 65 to 75 tons. In parts where hydraulic riveting cannot be used, the rivet holes will be coned on the driven side 1-16 inch.

Seams will be calked on both sides in an approved manner. All joints will be as shown on the drawing.

Each furnace will be in one piece and corrugated. The thickness and the diameter will be as shown on the drawing. They must be practically circular in cross-section at all points. They will be riveted to the flanges of the front head and to the combustion chambers, as shown.

There will be manholes in the boiler of such size and location as shown on the drawing. The top manhole will have a stiffening ring, as shown. The manhole plates will be of cast steel in dished form, except the top plate, which will be made of steel plate, "Class B." Each plate will be secured by two wrought-iron dogs and two 1⅜-inch studs, screwed into the plate (twelve threads to the inch), fitted with collars, and riveted on the inside, and fitted with nuts for setting up on the outside. Each plate will have a convenient handle, and all plates, dogs, and nuts will be plainly and indelibly marked to show to what holes they belong.

The grate bars will be of cast iron and of an approved pattern. They will be so fitted as to be readily removed and replaced without hauling fires. The bars at the sides of the furnaces will be made to fit the corrugations. The bars will be made in two lengths, resting on the dead plate in the front and on the bridge wall in the rear of each furnace. They will be supported in the middle by an approved framework made to fit the corrugations. No holes will be drilled in the furnace for securing the furnace fittings. The area of opening between the grate bars will be about 40 percent of the grate area.

The bridge walls will be made of cast iron, as shown, and so fitted as to be readily removable. They will be covered at the top with approved fire bricks laid in cement. The area of opening above bridge walls will be about 16 percent of the grate surface. The tops of the bridge walls will be slightly crowned.

The furnace fronts will be made with double walls of steel, bolted to a sectional cast-iron frame. The space between the two walls will be in communication with the fire room. The inner plate of furnace front will be perforated as may be directed. The dead plates will be made of cast iron and so fitted as to be easily removable. The door openings will be as large as practicable.

The furnace doors must be protected in an approved manner from the heat of the fires. The perforations in the doors and lines will be as directed. Each door will have a small door near its lower edge for slicing the fires. There will be two wrought-iron hinges to each door and the latches will be of wrought iron. There will be an approved arrangement fitted to each door to prevent them from sagging, and also to hold them open when firing. The furnace-door liners will be made of cast iron ⅝ inch in thickness.

Ash pans of ¼-inch steel plate, reaching from the front of the furnace flue to the bridge wall, will be fitted to all the furnaces. The edges of the ash pans will be made to fit the corrugations of the furnaces.

The ash-pit doors will be made of 3-16-inch steel plate, stiffened with angle or channel bars. They will be furnished with suitable buttons, so as to close the ash pit tightly when the furnace is not in use. Each door will have two wrought-iron beckets to fit hooks on the boiler front. Wrought-steel protecting plates ⅜ inch thick will be fitted around the boiler front, sides and passages, as before specified, to serve as ash guards.

A lazy bar with the necessary lugs will be fitted to the front of each ash pit, and there will be three portable lazy bars for the furnaces.

The uptake will be made of double shells of steel No. 8 U. S. S. G., built on channel bars and stiffened with angles and will be bolted to the boiler head and to the smoke-pipe base. Outside of the uptake will be a jacket inclosing a 3-inch air space. This jacket will be made of No. 12 U. S. S. G. steel. The space between the plates of the uptake will be filled with magnesia blocks containing not less than 85 percent carbonate of magnesia.

The uptake doors will be made of double shells of steel of the same thickness as the uptake and will have an air jacket like the uptake. The space between the shells will be filled with magnesia blocks. The hinges and latches will be made of wrought iron. Each door will have an eyebolt near its top for handling and one near the bottom for convenience in opening.

The boiler will rest in two approved saddles, built up of plates and angles. It will be secured to the angles by standing bolts screwed into the boiler shell, with nuts inside and outside, the inside nuts setting up on snugly fitting washers, with cement joints. These bolts will fit holes in the angle bars of the front saddle snugly, but pass through enlarged holes in the angle bars of the back saddle to allow for expansion. Chocks built up of plates and angle bars will be fitted at each end of the boiler, as approved, so as to prevent any displacement of the boiler. The boiler will be secured, in addition to the above, by four 1½-inch holding-down bolts connecting cast-steel palms bolted to the boiler shell and riveted to tank tops and reverse frames of the vessel, as approved.

The boiler will be clothed with magnesia blocks, securely wired in place and covered with galvanized iron, in an approved manner.

Boiler Attachments.

The boiler will have the following attachments of approved design, viz., one main steam stop valve, one auxiliary steam stop valve, one whistle-steam stop valve, one dry pipe, one main-feed check and stop valve with internal pipe, one auxiliary-feed check and stop valve with internal pipe, one surface blow valve with internal pipe and scum pan,

one or more bottom blow valves with internal pipes, a twin-spring safety valve, one steam gage, one glass and one reflex water gage, both of the automatic self-closing type; four approved gagecocks, one sentinel valve, one salinometer pot, one or more draincocks, one aircock and zinc protectors, with baskets for catching pieces of disintegrating zinc.

All the external fittings on the boiler will be of composition, unless otherwise directed, and will be flanged and through-bolted, or attached in other approved manner.

All cocks, valves and pipes unless fitted on pads or in other approved manner will have spigots or nipples passing through the boiler plates.

All the internal pipes will be of brass or copper, as approved, and will not touch the plates anywhere, except where they connect with their external fittings. The internal feed and blow pipes will be expanded in boiler shells to fit the nipples on their valves or will be secured in other approved manner, and will be supported where necessary and as directed.

Steam-Stop Valves.

There will be approved composition stop valves 6 inches in diameter for the main steam, 4 inches in diameter for the auxiliary steam, and 2 inches in diameter for the whistle steam, fitted to each boiler in an approved manner. These valves will close toward the boiler, and approved extension rods will be fitted to the hand wheels for the main and auxiliary steam-stop valves, so that they may be opened or closed from a location outside of the fire room space.

Dry Pipes.

The dry pipe for the boiler will be of copper, No. 14 U. S. S. G., and will be heavily tinned inside and outside.

The pipes will extend nearly the length of the boiler and will be perforated on the upper side with longitudinal slits or holes of such a number and size that the sum of their areas will equal the area of the steam pipe. The valve end of the pipe will be expanded into the main and auxiliary stop-valve nozzles, or will be secured in other approved manner. The pipes will be closed to the boilers, except for the slits or holes above mentioned.

Feed-Check Valves.

There will be an approved main and an auxiliary feed-check valve on the boiler, placed as shown on the general arrangement.

The valve cases will be so made that the bottom of the outlet nozzle shall be at least ½ inch above the valve seat. The valves will be assisted in closing by phosphor-bronze spiral springs. The valves will have hand wheels and approved gear where necessary for working them from the fire room floor.

There will be an approved stop valve between each check valve and the boiler.

Blow Valves, Blowpipes and Pumping-Out Pipes.

There will be an approved 1¼-inch surface blow valve on the boiler, located as directed. The valve will close against the boiler pressure. An internal pipe will lead from the valve to near the water line in the boiler and will be fitted with a scum pan.

There will be one or more approved 1½-inch bottom blow valves on each boiler, located as directed. The valves will close against the boiler pressure. Internal pipes will lead from the valves to near the bottom of the boiler, as required.

An approved 2-inch copper pipe will connect the bottom blow valves with an approved sea valve located where directed in the same compartment. These pipes will have 1¼-inch nozzles for the attachment of pipes from the surface blow valves, and also 2-inch nozzles for the attachment of the boiler pumping-out pipes. All joints will be flanged joints, as approved.

There will be a nozzle with a flanged valve on the sea valve, above mentioned, for the connection to the hose for wetting down ashes.

An approved 2-inch pipe will connect the bottom blow pipes to the salt-water suction manifold of the auxiliary feed pump, and so arranged with approved valves in the various pipes that the boiler may be pumped out when desired. The suction pipes for the injectors will be taken off the pumping-out pipes by means of approved branches, valves, etc.

Safety Valves on Boilers and Escape Pipe.

The boiler will have an approved twin-spring safety valve (two valves), each 3 inches in diameter, and they will be located as shown on the general arrangement.

Each valve will have a projecting lip and an adjustable ring for increasing the pressure on the valve when lifted, or an equivalent device for attaining the same result. They will be adjustable for pressure up to the test pressure. Gags will be furnished with each safety valve so that the valves may be held seated when testing the boilers.

The springs will be square in cross-section, of first quality spring steel. They will be of such a length as to allow the valves to lift one-eighth of their diameters when the valves are set at 180 pounds pressure. They will have spherical bearings at the ends, or they will be connected to the compression plates in such a manner as to insure a proper distribution of the pressure. They will be inclosed in cases so arranged that the steam will not come in contact with the springs.

The spring cases will be so fitted that the valves can be removed without slacking the springs. The valve stems will fit loosely in the valves, to bottom below the level of the seats, and will be secured so that the valve may be turned by a wrench or crossbar on top of the stem. The valves will be guided by wings below and in an approved manner above.

The valves will be fitted with approved mechanism for lifting them by hand from the fire room floor or the engine room, as directed. The mechanism for each set of valves will be so arranged that the valves will be lifted in succession. All joints in the lifting-gear mechanism will be composition bushed.

The outlet nozzle will be in the base casing, so that the joint at the escape pipe will not have to be broken when taking the valves out. The casings and valves will be made of composition, the valve spindles of rolled bronze, and the valve seats of solid nickel castings screwed into the top of the composition base. A drain pipe leading to the bilge will be attached to each safety-valve casing below the level of the valve seat.

There will be an approved 7-inch copper escape pipe,

located abaft the smoke pipe, extending to the top, finished and secured in a neat manner. This pipe will have branches leading to the safety valves on the boilers, and the auxiliary exhaust pipe will also lead into the escape pipe, as elsewhere specified.

Steam Gages for Boiler.

There will be an approved steam gage for the boiler, located and secured in a conspicuous position on the fire room bulkhead, as directed, so as to be easily seen from the fire room floors. This gage will have dials 8½ inches in diameter and will be inclosed in polished brass cases. The gage will be graduated to 360 pounds pressure and so adjusted that the needle will stand vertical when indicating the working pressure; this point will also be plainly marked with red.

The valve connecting the steam-gage piping to the boiler will be fitted with a guarded valve stem and a detachable key or wrench for opening or closing the same; also with an approved opening for the attachment of a test gage.

Boiler Water Gage.

There will be one approved glass water gage and one approved reflex water gage, both of the automatic self-closing type, fitted to the boiler, as directed. Each gage will be placed in plain sight, near the front of the boiler. The shut-off cocks will have a clear opening of at least ½ inch in diameter, and will be packed cocks, with approved means for operating them from the fire room floor.

The blow-out connections will be valves and will have brass drain pipes leading to the bilge, with union joints, ½-inch iron-pipe size.

The glasses will be about 18 inches in exposed length. They will be ¾ inch outside diameter, will be surrounded by brass wire-mesh shields and protected by guards.

Reflex gages must be designed to fit the water-gage fittings, so that the two kinds will be interchangeable.

Gage Cocks.

There will be four gage cocks of an approved pattern fitted on the boiler, with approved means of operating them from the fire room floor.

Each cock will be independently attached to the boiler. The valve chamber will have two seats, the inner one formed in the casting, and the other movable, screwed into the casting and furnished with a handle. The valve will have two faces and will be closed by screwing down the movable seat and opened by the pressure in the boiler when the outside seat is slackened off. There will be a guide stem on each side of the valve, the valve and stem being turned from one piece of rolled manganese, phosphor, or Tobin bronze. The stem will be circular in section where it passes through the movable seat, and the outer end of stem will project ¾ inch beyond the movable seat and will be squared for a wrench. The inner end will be of triangular section. The opening of the valve will be at least ⅜ inch in diameter and the discharge from the chamber will be at least ¼ inch in diameter.

The gage cocks will be spaced about 4 to 5 inches apart, as directed, and each set will have a copper or brass drip pan and a ¾-inch brass or copper drain-pipe connection leading to the bilge.

Sentinel Valves.

The boiler will be fitted with an approved sentinel valve at the front end ½ square inch in area. It will have a sliding weight on a notched lever and will be graduated to 190 pounds pressure.

Salinometer Pots.

There will be approved salinometer pots, fitted with brass hydrometers and thermometers, connected to the boiler, as directed. They will be located in the fire room or where required.

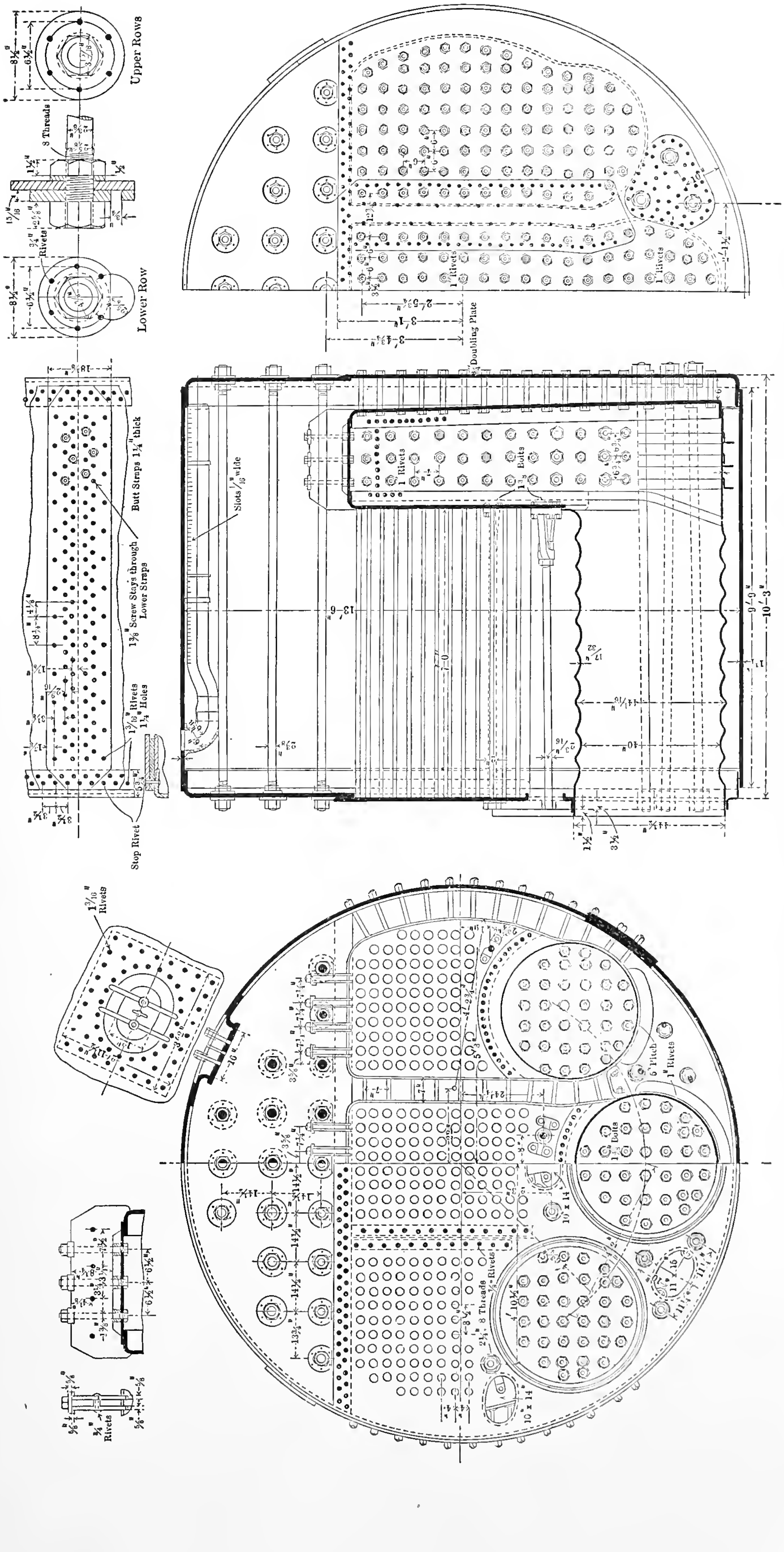
Boiler Drain Cocks and Aircocks.

The boiler will have one or more approved drain cocks, placed so as to drain the boiler thoroughly.

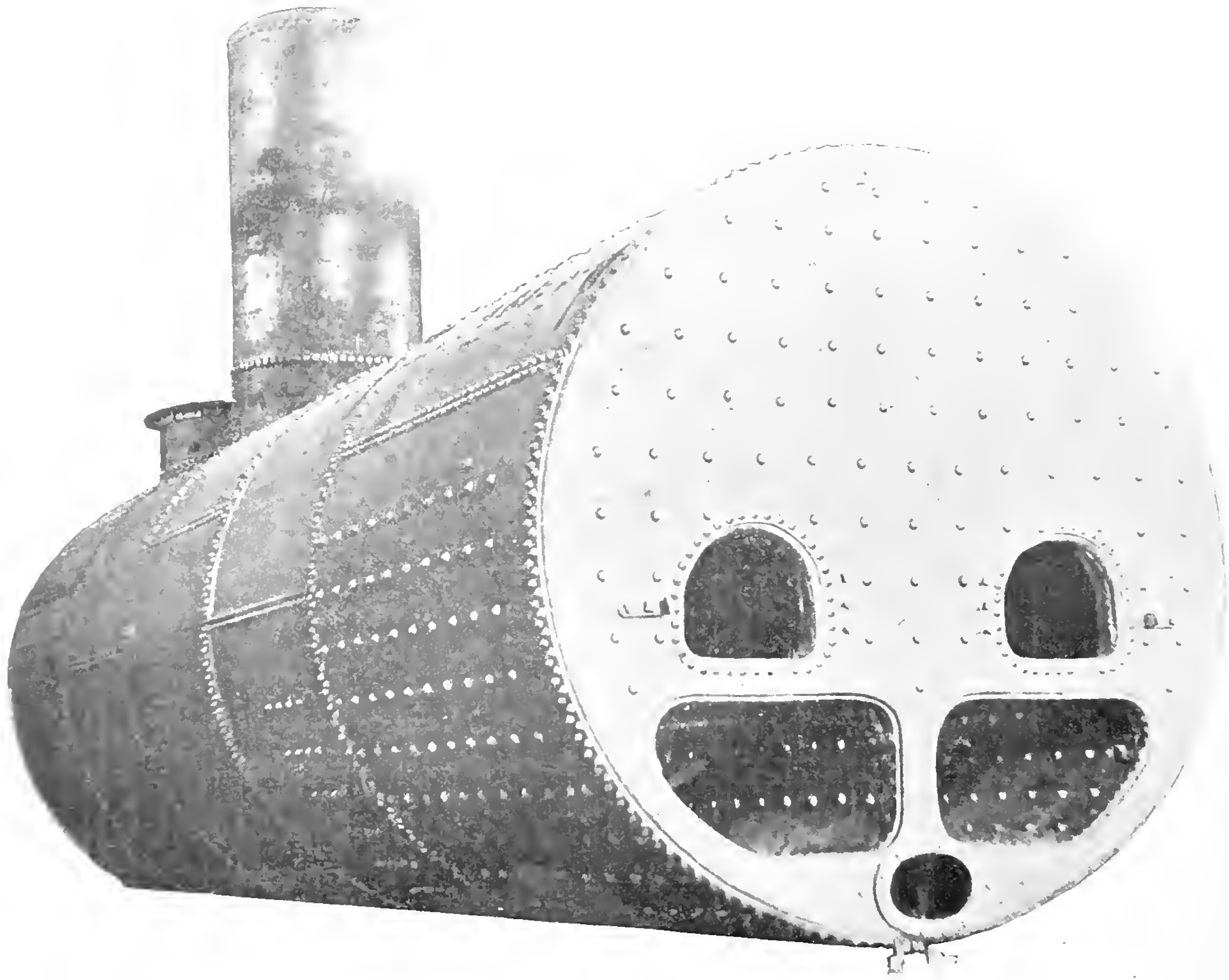
The boiler will have at the highest point an approved ½-inch aircock.

Zinc Boiler Protection.

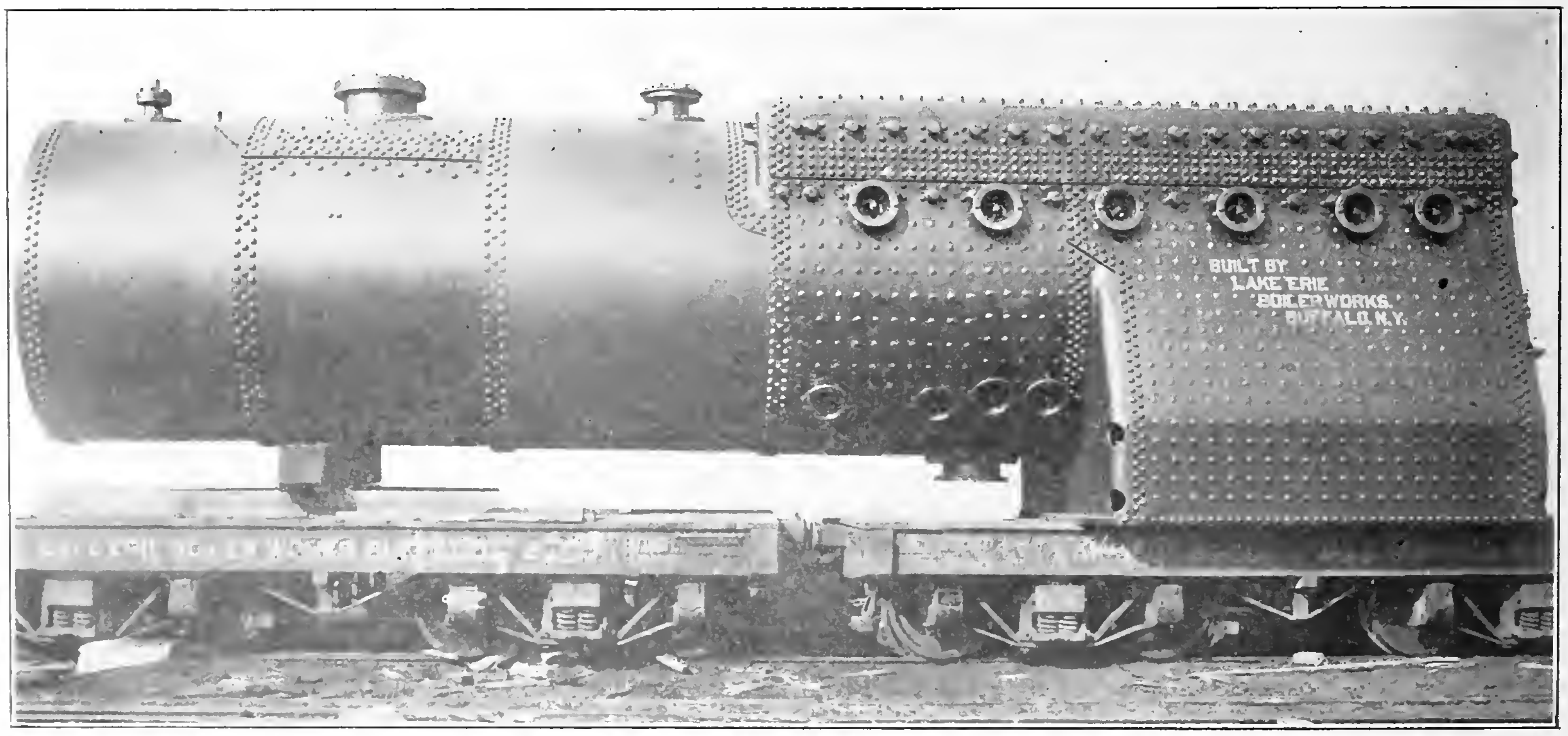
Zinc for the protection of the boiler will be held in baskets suspended from the stays, or as approved; these baskets will be made of wrought iron, perforated on the sides and solid on the bottom. The baskets in each boiler will contain sufficient rolled zinc to make the total quantity for the boiler not less than 100 pounds for each 15 square feet of grate surface, and the baskets will be distributed as directed. Each strap for supporting the baskets will be filed bright where it comes in contact with the stays, and the outside of the joint will be made water tight by approved cement.



THREE-FURNACE, SINGLE-ENDED SCOTCH BOILER, WITH DETAILS OF STAYS, CROWN BARS, RIVETING AND MANHOLE DOUBLING PLATE.



AN INTERNALLY FIRED RETURN FLUE MARINE BOILER, 9 FEET 8 INCHES DIAMETER BY 28 FEET 6 INCHES LONG, FITTED WITH STEAM DOME 3 FEET IN DIAMETER BY 8 FEET HIGH, TWO FURNACES 3 FEET 11 INCHES WIDE BY 7 FEET 7 INCHES LONG, TWELVE FLUES 13½ INCHES DIAMETER, TWO FLUES 31¼ INCHES DIAMETER, TWO FLUES 10 INCHES DIAMETER, STEAM PRESSURE 50 POUNDS PER SQUARE INCH.



A LARGE STATIONARY BOILER OF THE BELPAIRE LOCOMOTIVE TYPE, BUILT TO SUPPLY STEAM AT HIGH PRESSURE FOR HIGH-DUTY PUMPING ENGINES; TOTAL WEIGHT OF BOILER 75 TONS. LENGTH, 33 FEET 7 INCHES; DIAMETER, 90 INCHES; TWO FURNACES EACH 10 FEET 6 INCHES LONG BY 4 FEET 6 INCHES WIDE; 201 3-INCH TUBES; HEATING SURFACE, 3,032 SQUARE FEET; GRATE AREA, 68¾ SQUARE FEET; RATIO, 44.1.

REPAIRING LOCOMOTIVE AND OTHER TYPES OF BOILERS

CHAPTER I.

In this series of articles the author proposes to deal with the repairing of locomotive and other types of boilers, especially the water-tube. We will begin with the locomotive boiler, and will assume that three locomotives have arrived in the shop for a course of widely different repairs. We will call these locomotives Nos. 1, 2 and 3. No. 1 needs a set of half-side sheets, a half-door sheet, a front flue sheet and a smoke-box bottom. No. 2 needs two back corner patches, a couple of patches on the side, a back flue sheet and the rivets in door sheet to be backed out and redriven, and the mud-ring is cracked. No. 3 needs a new set of radial stays, broken stay-bolts to be renewed, flues replaced, a patch on the top of the back flue sheet, a belly patch, a new stack, bulge in fire-box to be heated and layed up, and bushings between stay-bolt holes. In different shops, with their respective conveniences, the manner of procedure will be slightly different.

Taking engine No. 1, in a shop fairly well equipped with pneumatic appliances, the half-door sheet would be removed first, and this will enable the sides to come out by ripping in a horizontal direction only, while if left in, it would be necessary to cut till the flange of either the door or flue sheet was reached, and then would rip down to the mud-ring. In taking out the door sheet the first step is to decide how high up it is to be cut off; if half-way up the door hole is left in. Mark an even number of rivet holes up from the center on each side and draw a line around the knuckle of the flange and continue toward the side sheets on each side, keeping in mind to have an even slope and all stay-bolts out of the line of rivets.. Count the same number of rivets up from the mud-ring on each side till you are in line with the slope you wish to cut; if there are any stay-bolts in the way, move a rivet higher or lower, till you can cut across and remove the bolt with the defective portion; it will be a matter of judgment, based on practice, to overcome this difficulty in every case. After having closely center-punched this line, and noticed that the lap is up high enough not to interfere with the removal of sides, and also that four thicknesses of iron will not come together, cut along the center marks with a cape chisel and ripper, then center and drill out the rivets in the flange from mud-ring up, as well as those in the door hole. In both cases go one rivet higher than the cut for the lap rivet. After having gouged out the burrs and knocked down the rivets, center-punch the stay-bolts on the outside of back head that are to be removed with the defective portion of door sheet. On one side of the inside sheet drill an outside row from mud ring up to cut; this is to enable the sheet to turn freely and prevent the bolts from catching against the end of side sheet. After having drilled all necessary bolts and knocked the rivets out of mud ring, drive a lap wedge between ring and sheet at bottom far enough to enter a longer wedge with more taper. A wooden wedge about 18 inches long and 3 inches wide, tapered from 4 inches to nothing, will, if backed with sheet iron, give good results. Drive this wedge up from the bottom until there is quite a strain on the sheet, then take a handle punch, and working through all the drilled holes from the outside, break the remainder of the drilled bolts out with a sledge; as the bolts break it will relieve the strain, making it necessary to insert more wedges from top and bottom till all bolts are broken loose from the back head. Now on the side on which the bolts were drilled from the inside, wedge the sheet clear out from the mud ring, and working a punch bar from outside holes, top and bottom, on one side only, gradually work the flange clear till it drops in the pit. Fig. 1 shows how the wedges are placed, what holes are drilled from the inside, and how the metal is cut at top to avoid stay-bolts.

We are now ready to remove the sides. Draw a line parallel with the mud ring on the side sheet at sufficient height to remove the defective portion, and to keep lap as far from fire as possible, and cut to just clear the upper row of stay-bolts and rivet line to catch corresponding rivets in both flue and door sheets without deviating from the horizontal, as shown in Fig. 2. If the flue and door sheets are parallel, and at right angles to rivet line in mud ring, it will be much easier to lay out a new sheet.

The first step in removal will be to center and drill all stay-bolts from the outside that come within the zone on both sides of the boiler; if the mud ring rivets are driven counter-sunk, it will be necessary to drill all of them at least as far in as the counter-sunk portion. If they have been drilled squarely with a ¾-inch drill for a 13-16 rivet, it will not be necessary to gouge out the counter-sunk burrs, for when a punch is applied in the hole and hit with a sledge, if the rivet is not extremely tight, it will burst loose the counter-sunk portion and also force the rivet out. It will be well, however, before the rivets are punched out of the mud ring on the sides, to put two bolts in that portion in connection with the back head, so that when the rivets are all out of the sides, the ring will not sag and unnecessarily strain the flue and throat sheet. However, in this particular case, it will be as well to drill out the few remaining rivets in the back flue sheet and drop the mud ring entirely. It will make things much easier when riveting is begun, assuming that the mud ring is out and the back flue sheet rivets drilled out to the required height, and stay-bolts drilled a sixteenth beyond the sheet on outside. They will be burst loose with a punch, and wedged out like the door sheet. In some places a crow-foot bar is used, and two men working from inside the shell will break the bolts down through the water space; in either case the bolts will have to be drilled outside just the same, and all burrs removed with a gouge. With the door sheet removed, it will be easy to drop the two sides by working the back ends towards the center till there is sufficient space in the clear to enable front end to pass outside of flue sheet flange and drop to the floor.

Fig. 3 is a side view of the front end. It will be noticed that the smoke-box is butted to front end and held in place by a 1 by 8-inch wrought-iron ring. Before the flue sheet can be removed it will be necessary to cut off the front section of front end, including this ring, for the reason that the internal diameter of ring is less than outside diameter of flue sheet. The

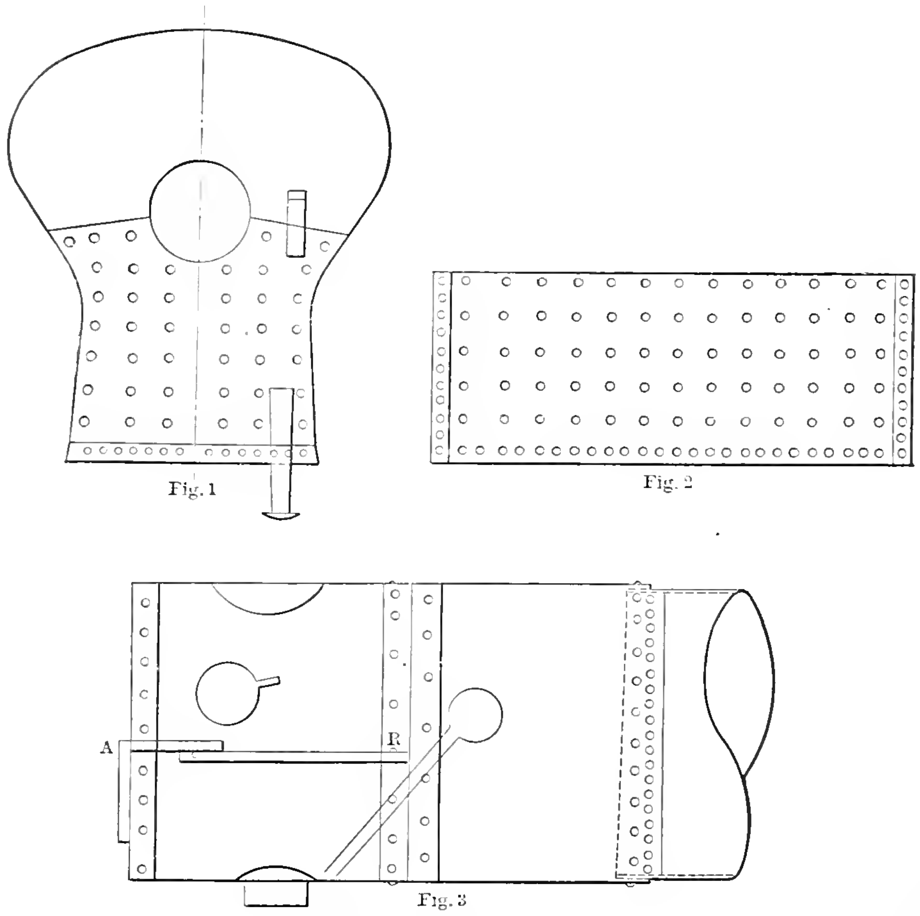


Fig. 1 Fig. 2 Fig. 3

REPAIRING LOCOMOTIVE AND OTHER TYPES OF BOILERS.

most convenient method is to swing a block and fall over the central portion, cut out the inside row of rivets and jack front section and wrought-iron ring out in one piece, then after having cut and backed out the rivets in the flue sheet it will also be necessary to cut off about half the rivets along the bottom in the row that holds the front end to the boiler shell, because on account of their large heads the flange will not clear them enough for the sheet to turn.

Assuming that this has been done, the next step will be to drive two drift pins diametrically opposite each other, and at a height of about the horizontal center line of the shell. These will act as hinges and enable the sheet to turn freely after having once started from its seat. After turning to a horizontal position, remove the drift pins and the sheet will then generally slide out without any further trouble.

Putting on a half-bottom to the smoke-box will be much easier now that it is disconnected from the boiler as it can be rolled to a convenient place and marked for cutting. To mark the cut, place the long blade of a square jamb against the door ring as shown at *A*, and with a straight edge against top of square, raise or lower till cut comes squarely in to rivet *R*. Mark the line with crayon and proceed in like manner on the other side; sometimes the ring is warped, and in order to be sure you are taking a square cut, get a piece of band, saw off convenient length, and passing it around the smoke-box on each side, mark the exact center of rivet that cut goes into, then transfer this measurement to the front, if marks coincide it is safe to assume that cut is square. After having removed the defective portion, take a straight edge and holding it against the raw edge, chalk the high spots, if they are as much as 1/8 inch off, chip them level, if only a 1-16 or 1-32, upset with a hammer and smooth and bevel slightly with a file; keep this up till the straight edge meets the cut well along on both sides, and we will now be ready to lay out the new bottom.

Procure a strip of wood or some other flexible material the exact thickness of the metal to be used, about 2 inches wide and clamping it around the front ring in the space the patch is to occupy, mark off to the exact dimensions and with a scriber mark through the ring the rivet holes, and when this strip is straightened out it will be the exact length of sheet in the front. Mark back length and rivet holes the same way, and if cut was made square the front and back lengths will be equal, and the width can be measured with a rule. Procure a sheet the right width if possible, and of sufficient length to allow of bevel shearing at each end. With the strips just mentioned mark off the rivet holes on each side, and at each end lay out a row of holes for the butt strap, which are to be countersunk. Cut the cinder hopper off the old piece, and with a piece of tin cut and bent to the radius mark through the casting the necessary bolt holes, straighten out the tin and locate the hopper hole on the new sheet, then, while the puncher is getting out the work, strip off the butt strap holes and allowing about 1¼ times the rivet diameter from the edge, locate the rivet line on each side, then center, screw, punch and countersink. Make the butt strap out of material one and one-eighth times the thickness of new plate. On account of the erosive action of the cinders, the old plate will always be thinner than the new, so to make a smooth joint outside, a thin strip is to be placed between butt strap and sheet at top half only, but on both sides. If the puncher has our sheet done, we will procure a sweep of the desired radius and roll the sheet to this curve on the inside, taking care that no flat places are

left in the end, and that sheet is set square with the rolls; after rolling, that part that was sheared bevel at each end will now be upset sufficiently to form a burr, so that the sheet when riveted into place will look more pleasing to the eye; this burr is hammered flat and the surplus metal fills the little interstices, and when carefully done the front looks like one continuous band of metal.

As the process of bolting and riveting up this patch is simple, we will again turn our attention to the side sheets. As the sides go in before the door sheet, we will lay them out by squaring up a sheet of the required dimensions. Mark off the exact length of old sheet at top and bottom, and to get correct height and fair rivet holes, bend a piece of ⅜ by 1 inch iron till it conforms to the shape of the inside or water space surface of the flue sheet. Mark through the rivet holes with a scriber and allow at top an amount for riveting and lap. Straighten out the strip and transfer measurements to the new sheet, and do the same for back end. The stay-bolt holes can be located by stripping the outside rows, and then transferring to sheet and connecting opposite points with solid lines; their crossings will be stay-bolt centers. After sheet is punched, roll to same shape as old one and countersink the top row of rivet holes so that rivets can be driven flush. To enter sheets in place, fasten a scaffold bolt to top of fire-box and hoist sides in to position with a chain block. Assuming that the flanger has the flue and door sheet done, they are now to be put in position and we will then be ready to rivet. Before commencing to drive, however, be sure that the slack places are pulled out of the sheets, and if the corners don't lay up well it will be necessary to heat and upset into place with a fuller.

There are several ways of holding on the rivets in the water space; perhaps the easiest is with the pneumatic tool. It consists of a wrought cylinder attached to an air supply pipe and contains a piston die with a countersunk head to fit rivet, so that when air is turned on it engages the rivet head and the reaction is against the outside sheet. Wedge bars are mostly used, however, and they may be worked from inside or outside; if worked from the inside of the shell, have the bar made the length of fire-box plus 2 or 3 feet, and have the wedge the thickness of water space minus the rivet spoon, and minus 1 inch; this inch is to be used for a back liner and will ride on bolts placed through the water space. If worked from the outside, it will be necessary to spring sheet off from the bottom enough to allow the wedge to work freely; a sheet wedge with a longer taper will have to be used in this case, so that when rivet is applied with a spring, tongs cup put in place and wedge driven home, it will not be too long to interfere with the free use of a sledge. All the rivets in the water space can be driven this way, and as a precautionary measure the wedge bar should have a flat space on the end of about 4 inches, and also should have just taper enough to put a couple of hundred pounds strain on the rivet head; if strained much more than that, it bulges the sheet, and when wedge is released the sheet in straightening will have a prying effect on the countersunk rivet heads which, if they do not pop off while calking, the seam will be very likely to give trouble afterwards.

The flat space on the bar will allow it to ride when in position and also enable the striker to judge the degree of strain. Putting in the water-space bar, riveting up front flue sheet and connecting smoke-box to front end being comparatively simple, we will next take up Engine No. 2.

CHAPTER II.

Taking engine No. 2 and assuming that one man does the work, for convenience of illustration, we will take down the grates and ash-pan and remove the flues before commencing on the large work. In this case, while the motor and drill are connected, it will save time to do all the heavy drilling first. To remove crown and back flue sheet, we will center and drill all the stay-bolts in the outside of throat sheet and afterwards break them down on the inside with a crow-foot bar. In drilling out the rivets around the flue-sheet flange, a handy appliance is shown in Fig. 4. It is made of ⅝ by 4-inch spring steel, split on one end about 4 inches, then opened out and a finger put on each leg. In going around the sides and top it is hooked in the flue holes and will accommodate any position of the motor.

In drilling out the bolts and strays in the crown sheet the most convenient method of securing backing for the motor is to cut two fairly heavy planks just long enough to reach across the fire-box above the O-G bend. Place one at each end; then a plank placed lengthways on top can be shifted to suit the position of the motor. After drilling out and knocking down all the necessary bolts and rivets, the flue sheet is removed by knocking the top towards the front far enough to allow the bottom to turn sideways between the water spaces. When this sheet comes loose it does so with a jump, and to keep anyone from being hurt it is customary to tie it with a rope to the dry pipe, or to a rod laid across the dome hole. The crown sheet can now be dropped either by pulling out or tilting one side until the opposite edge comes in the clear, and then lowering to the floor.

Before proceeding with the other work we will lay out and flange the crown and flue sheets. In most places where much of this work is done, flat sheets are kept in stock a little larger than the required size, to allow for trimming. Fig 5 shows one of these sheets with the flue sheet in position ready to mark off. To lay out, have the bottom of flue sheet extend within ⅛ inch of edge of the flat plate; see that the old sheet is laying level and with flanged edge turned down to meet new sheet all around. If the old sheet has wings at the mud-ring corners it will be necessary to block up the other end until both sheets have their planes parallel. Then with a sharp crayon pencil mark the outlines of the old sheet on the new, and it will also save time afterwards to mark the belly-brace holes and the crooked outside stay-bolt holes with a long tit punch, and using the old holes as guides.

Before the old sheet is removed, take a square and go around the edges, and you will find at the top or crown sheet end that the bottom does not meet the square by an amount from ¼ to ¾ inch, varying in proportion to the number of tube holes and the number of times they have been reset, as *A*, Fig. 6. To find the difference a set of tubes will have in affecting the length of a sheet is easy by actual experiment.

With the first set of new tubes you have occasion to put in, tram the width and length of flue sheet carefully before the coppers are rolled, and center-mark these measurements on the side sheet. After the flues are completed, tram again and you will find that the sheet has become longer and wider, from 3/16 to ⅜ inch, according to the amount the tubes have been worked. After a few cases like the above the steel reaches its elastic limit, and does not return to its former position; and on account of the crown sheet with rigid sling-stays and downward pressure holding the edge of the flange, it soon begins to cup, and assumes the position shown in the accompanying drawing Fig. 6.

Now in laying out the new sheet around this part, flangers differ in opinion as to whether the new sheet should be marked from the root of flange or the edge of sheet. In this case we will mark it from the edge of sheet, because, first, it will be a little easier to put in, and next, when it starts to grow the second time it will not further strain the crown sheet by having the advantage of a ½-inch start, providing the old crown sheet was left in. After marking the outlines, remove the old sheet and center-punch lightly; assuming that the flange has an outside radius of 1½ inches, it follows that the circular part of the flange will begin 1½ inches on the inside of this line. As the radius of the center of the flange is 1¼ inches, then $1.25 \times 3.1416 \div 2 = 1.9635$ inches, to be marked and center-punched from the inside line. To this add an extra amount equal to the depth of flange. While correct in theory, this rule is not used much in practice, except for heads and flanges of from 3 to 5 inches radius. Another rule to get the flange line for small radius is to subtract twice the thickness of metal from outside depth of flange wanted; or again the crayon line can be center-marked and brought down with the flange one thickness of metal. An experienced flanger may often do this way and bring the sheet out all right. As the flange gathers on a convex radius and loses on a concave one, it is customary to subtract a small amount around the top, and add a little extra to the concave part shown at *c*, Fig. 7.

Before flanging, it is customary to punch all the stay-bolt holes, braces and flue centers. The flue holes are shown partly laid out in Fig. 7. Apparently two methods are used; although not alike in appearance they are similar in principle, and owe their origin to the rule: One-sixth of the circumference of a circle stepped off equals the radius. To lay out, locate the center line on new sheet, and with dividers set to spacing of center to center of old holes, step off on center line, and center-punch, taking care to start the same distance from the bottom as the space is on old sheet, without changing dividers, and with each found point as center, scribe arcs to the left, which intersect as shown. Continue as before till outside is met. On the right side as noticed, 60-degree angles are erected; their crossings denote flue hole centers, and if laid out correctly will coincide with left half. The holes thus found are not generally made full size till after flanging, especially as the outside holes have a tendency to become oval in the process of flanging.

In flanging by hand over a former, the flat sheet is first laid in position with the edges projecting over the former the required amount to form flange. The clamp is then let down, and a couple of lugs are bolted to the face of the sheet on the other side, to butt against the clamp. The sheet is then chalked where it is to be heated, and also several guide marks are chalked on the sheet and clamps so that when coming out in a hurry with the heat it will be an easy matter to set the work in its exact position. About two feet at a time is heated and flanged, in this way care being taken not to heat the metal back too far, nor to hammer the flange more than is needed. Both of these conditions coming together will cause the sheet to buckle on account of unequal strains set up in the material. After flanging, the sheet is annealed by heating to a low red and allowing to cool slowly. In this final heat the buckles are removed by hammering on a face plate. The flue holes are then finished and the calking edge chipped bevel. The flange rivet holes are now marked from old sheet, drilled and countersunk.

The crown sheet is marked and flanged much the same as the flue sheet. If it is a crown-bar boiler, the four corners before flanging will be scarfed—that is, drawn to a feather edge—so as not to put too sudden an offset in the connecting sheets. Sometimes the sides are turned down cold, the only redeeming quality of this method is the low first cost. Compared with a properly-done job it is an inferior article. The crown sheet in this case, however, has a gradual roll. Perhaps the easiest way to get out the new sheet is to cut a sweep for the crown-sheet radius, and then run the old sheet through the straightening rolls. In the absence of such, a common roll will answer very well. Then clamp the old sheet on the new, mark, punch and roll, and the crown and flue sheet will be ready to put in. In the matter of corner patches, if there are four to be put in the fire-box, the two back ones are the easiest to apply; for in this class of engine no plugs are put in the back corner, and the door sheet is not so thick and hard to cut as the flue sheet. Cutting in a horizontal direction just above the first row of stay-bolts will generally take in all the defective material. In cutting down to the mud-ring, care must be taken not to have a square corner, and it will also make a better looking job to have the downward cut slope at an angle.

Before the patches are applied we will drill and V-out the rivet holes in the seam above the cut on door sheet, as shown in Fig. 8. Two or three times the diameter of the rivet is allowed to drive. In order to fill the countersunk and V, the hot rivet is applied in the top hole with a spring tongs. The cap *c* is then set on the head, and the wedge *A* driven home. This wedge has a part turned over square on the end of the handle to admit of its being more readily removed when the rivet is finished. As the rivets are being driven lower down they will be much easier to hold, and care must be taken not to drive the wedge in too far, as it will crimp the driven head of the last driven rivet and cause it to leak. No rivet is put in the bottom hole, as it is a lap-rivet hole for the patch. The sheet is scarfed very thin at this point, as shown by shaded portion, also at *E*. There are two reasons for doing this, either one of which would warrant its being done in almost

every case; first, it keeps three full thicknesses of metal from the fire, and again, as mentioned before, relieves the sudden offset.

Part of the cut-out for the patch is shown in Fig. 8, also the centers for describing the patch bolts. To locate these centers, mark ⅞ inch from the raw edge all around with crayon; then for 13/16-inch patch bolts, set dividers 1⅞ inches, and trial space this line. If it does not travel correctly the first time, open or close dividers slightly until it does come right. Then center the spacings, as they represent patch-bolt centers.

Now when the new patch is fitted to place, it will be impossible to see these centers; therefore some way must be devised to transfer these measurements. Two simple ways are shown; first, with dividers set (say) 6 inches, and with each point in rotation as center, scribe arcs which cut each other at *XXXX*. Then, when the patch is in position, and using *XXXX* as centers with same radius, scribe arcs that cut each other on the patch; when these are centered and drilled, they will correspond with the centers on old sheet. Another method is shown for the four bottom holes. Where dividers are not to be had, simply mark with a rule or straightedge a standard distance (say 10 inches), center-mark and connect the two points with a solid line.

The process of fitting up these corner patches requires judgment and experience. No two men will do all the work just alike. Nearly every boiler maker has little short-cuts learned from experience. In a general way the length and width are taken, and a piece of metal cut to this size. Now the patch not only has to be bent to the radius of the corner, but also offset inward at the bottom. The old-fashioned way, and one that still makes the best and neatest looking job, is to offset the material to follow the cut all around. The method used mostly nowadays is to offset on the bottom only, over a piece of ⅜ or ½-inch stuff, clear across in a straight line to within 2 inches of the edge on each end; then again heating and putting crossways in the clamp, and bending over to fit the corner. During the last operation it will be noticed that the offset portion has a tendency to crimp down in the clamp. To prevent this, bend a strip of ⅜ or ½ by 2½ inches to the curve of the mud-ring, putting this in the clamp and setting the patch for final heat. Fit up the offset portion to this curve.

It will also be necessary to lay a piece of ⅜-inch material on the body of the patch; if this is not done, the clamps will have a bearing on the small offset portion only, and will allow the patch to move or slew around while bending with a maul.

After flanging, the patch will be clamped to its position on the boiler, and one stay-bolt and two rivet holes will be marked on one wing only. Procure the necessary bolts, flatter, fuller and wrenches, and have them convenient to use. When the patch comes over hot, punch or drill these holes,

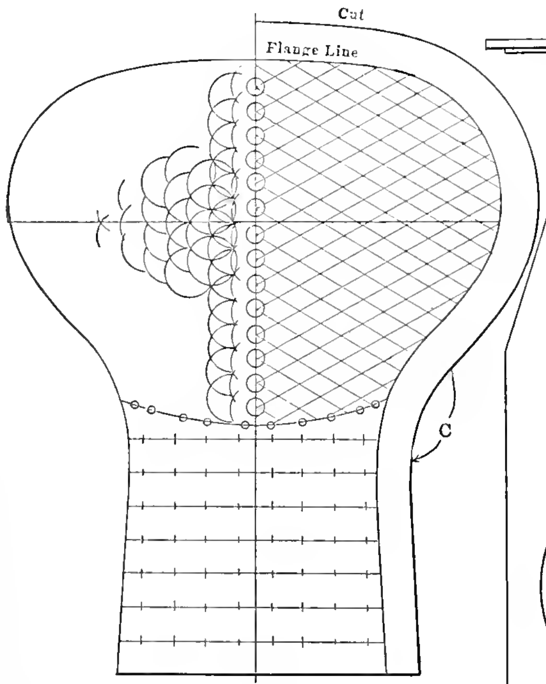
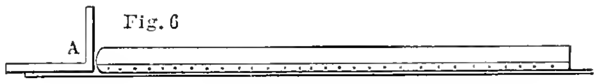


Fig. 7

Fig. 6


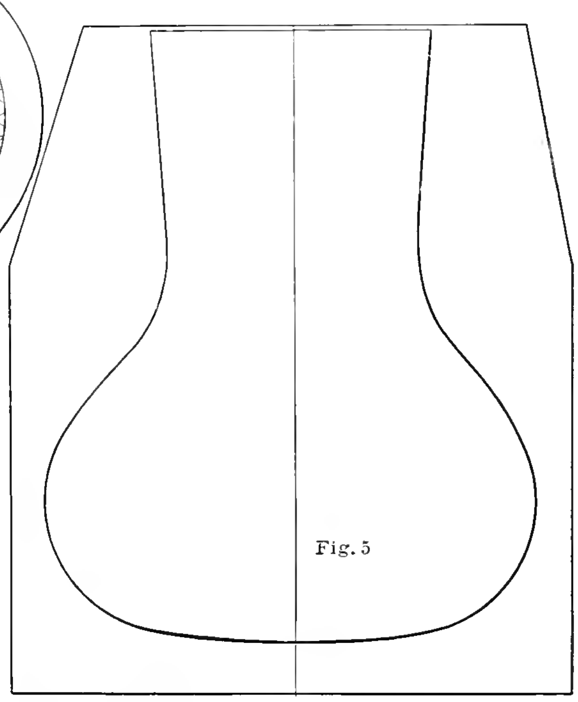


Fig. 5

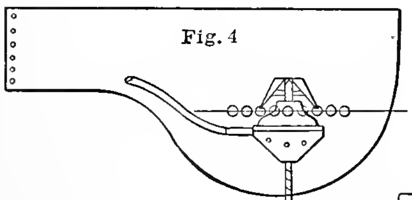


Fig. 4

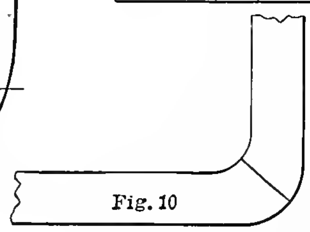


Fig. 10

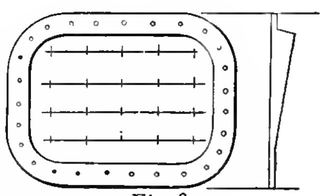


Fig. 9

then heat the punched side and the corner, not paying any attention to the other wing. When the patch is hot, bolt it up fast and tight in position, then, striking squarely against the cold wing, drive and upset the surplus metal into the corner. This is a much better way than fullering; however, some may think to the contrary. While the metal is hot keep your attention confined to the corner only, which is the real vital point. When the patch commences to lose its color it will no longer upset easily. Then it will be time to work the sides in and tighten up the bolts more. A stay-bolt and rivet hole can now be marked on the other wing. In marking the rivet hole be sure to allow a little for draw, as the iron has not yet entirely filled the corner. In this last heat both wings can be worked up, iron to iron, and the draw hole will still further crowd the iron into the corner. A fuller worked in the corner, both top and bottom, and a flatter on both wings will complete the laying up.

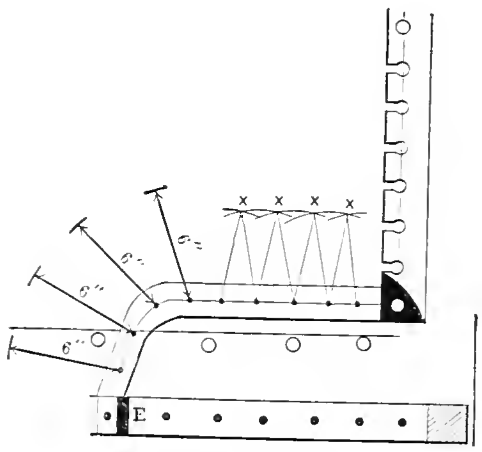
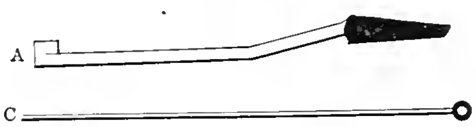


Fig. 8



The patch bolt holes are now marked as mentioned before; the mud-ring rivet holes are marked with a scriber from the outside. The surplus metal around the edges is also marked where it is to be cut off. It will be noticed that the wing on which the last heat was taken has sagged at the bottom and extends below the mud-ring about ¾ inch, according to length of wing. This sag is due partly to offsetting, and partly to door or side sheet being out of perpendicular. An experienced man will allow for this, and instead of cutting and offsetting his metal straight at bottom, will move upward on short wing something like ½ inch in 6. As all the holes in the patch cannot be punched, have them drilled 23/32 inch, with the exception of mud-ring holes, which are to be full size.

It is best to heat, patch and cut off surplus metal with a hot chisel. The writer has spoiled two patches in his checkered career by trying to shear them. It can be done though. Even a corner patch can be sheared all the way around on a common shears by blocking up under the blades with small pieces of iron. But it is a risky thing to do, although it saves much time and generally another heat. In trimming with a hot chisel around the corners, it is almost impossible to leave the edge exactly as it was before. For that reason a final heat is generally taken, and several more bolts put in all around. A few well-directed blows at the high spots will usually suffice to bring metal to metal all around.

However well the edges appear to be up, a view through the wash-out plug hole will show how the patch really fits. To insure fair holes, while the patch is in position and after it is cold, drill through the patch-bolt holes into the shell with a 23/32-inch drill. When this is done, have the patch holes reamed out to ⅞ inch, and countersunk for a 13/16-inch bolt. While this is being done you can tap the holes in the shell to suit the patch bolt. A patch of the box style is shown in Fig. 9. It owes its origin to the fact that the dished and surplus metals conform to the strains of expansion and contraction better than the straight kind. It is used largely on high-pressure engines by many roads. A copper gasket is generally placed just inside of the row of patch bolts. It is then not necessary to calk the outside edge, although in some places it is done as a precautionary measure. The method of flanging where no former is at hand is to get a piece of flat iron the thickness of the top depth of dish wanted, and draw it gradually down to nothing in the required length. Then, cutting sheet to required size with a small allowance for trimming, set hot sheet over former in the clamps, and flange one side at a time until three sides are down. The bottom is left straight so as not to form a pocket for sediment. The stay-bolt and patch-bolt holes are then put in as shown. It is bolted up to place and drilled as in preceding example. It will not often be necessary to heat this patch to lay up, as the two flat surfaces will pull up to a close contact without much trouble. Seven-eighth-inch patch bolts are mostly used, and they may be spaced 1⅞ centers, or as near as will come out even in traveling the rivet line.

Sometimes in countersinking the patch at the drill-press the holes will draw away from the center line. When this happens the patch bolt will not seat itself in a steam-tight joint. To make a better job, a countersink reamer is screwed into the bad hole. The cutting edge bears on the bad part only, and is fed by a small nut or thumbscrew. A few revolutions will make a good seat, and when patch bolts are pulled up with white lead, the manner of joint can be determined by the action of the lead in the countersink. It is customary to go around the outside edge and between the patch bolts with a light hammer and bobbing tool. This lays up the small bumps and helps to bring metal to metal. The patch bolts may now be twisted off, riveted over and worked down with a frenchman and facing pin. After calking with a round-nose fuller, the job will be complete. As a precautionary measure, however, if a copper-wire gasket is used it will pay to watch it closely by feeling through the stay-bolt holes. In some cases the vibration caused by working the patch bolts will spring the gasket from its seat and cause it to work out on one side and into the water space, even when soldered to the patch.

Fig. 10 shows a bottom view of a cracked mud-ring. In some cases a rivet is put in diagonally in the mud-ring, and the crack then generally stops at the rivet hole. In that case

the rivet is taken out and a number of plugs are drilled lengthways into the crack from the bottom and riveted over. Then, if the plugs have been drilled to intersect one another and afterwards worked down with a saddle tool, it will make a good job. The rivet hole is now drilled out again for the purpose of cutting off the plug ends that may stick through into the rivet hole. In case the ring is broken clear through, it is generally necessary to patch it. A piece of ½-inch steel is cut to the required shape, then fitted up, drilled and countersunk. The necessary holes in the mud-ring are drilled and tapped for the given size of patch bolt. In this case the patch proper is not tapped at all, but the countersunk portion is made to fit the angle of the patch-bolt heads, so that when the bolts are tightened it draws the patch more firmly to place. If the crack stands open at the bottom, a better job is made by dovetailing a copper strip into the crack before the patch is applied.

To cut out the dovetail a cape chisel and a one-sided diamond point are used. The cut is first made the necessary depth with the cape chisel, and afterwards concaved with the diamond point. A copper strip is then prepared and annealed by heating and cooling off in water. If the dovetail cut is smooth, the piece may be driven in endways. If not, it will have to be entered from the bottom and upset enough to fill the cavity. The cut is shaped as its name implies, and under ordinary conditions is sometimes used on repairs of this kind without a reinforcing patch at all, but when both are used it makes the job doubly secure, and well worth the extra trouble when costs and results are compared.

CHAPTER III.

On engine No. 3 the first step will be to remove the flues. This is generally done by cutting the ends off flush in the smoke-box, and in the fire-box chipping about two-thirds of the head off; this end is then ripped about 2 inches and closed in with a lifting tool; a flue-bar is then applied to each separate flue in the front end, and the flues are knocked out and back of the front flue sheet with enough clearance for each end to swing over to the large hole, which is generally located in the center row. Each flue is then pulled out through the large hole and cleaned by rolling in the "rattler."

The radial stays are removed by drilling both top and bottom; the top to be drilled at least the thickness of the sheet, and for the bottom the thickness of the head will generally suffice. The heads are then knocked off with a side-set or square punch. Two men working in the shell will now knock them out by applying a crow-foot bar on each stay, about one-third of the length up from the bottom. This will generally allow the bottom end to pull out of the hole before the top breaks. It is best policy to take out one of the sling stays also, so that when the back half of the crown sheet is reached a man can crawl in and hold up the bar. Otherwise a longer and heavier bar will have to be used, and a great deal of the force of each blow will be lost in vibration.

After the stays are down and the burrs removed, the holes are sometimes tapped with a long tap, as shown at Fig. 17-A. It has a square at each end, and is long enough so that when one end is cutting the other end is projecting through the corresponding hole in the other sheet, thus keeping the threads in line. If the holes in crown sheet tap out 1⅛ inches, and in the "wagon top" 1 inch, then two taps will have to be used. The bottom one is generally run up with a motor to full thread. A man on top will then back the tap down with a wheel or double ended wrench. While waiting for the tap to be cleaned, oiled and finishing its cut through the next hole, he may be tapping the top holes by hand. This method does not guarantee the top and bottom threads to match; therefore at times many bolts may have to be tried in one hole to procure a proper fit. While no individual bolt can have its thread out of alignment more than 1/24 inch, they will run from that much off to a perfect fit.

For this reason the wagon-top end of the bolt is fitted rather loose, so that when the bottom, which must be a steam-tight fit, commences to seat, the loose end will adjust itself slightly to the new conditions. A better method, but one which may consume more time, is shown by using the spindle taps in Fig. 17-B. Two shorter taps of the proper size are drilled through their centers and tapped twelve thread. A long piece of about ⅜-inch steel is threaded to fit the hollow, and when both taps are in place with the spindle through their centers it is next to impossible to cut threads that do not match. If the stays themselves, though, are threaded in a random way, no benefit will be derived from this method, for they will fit as in the first instance. However, many machines are in use which are constructed with this especial purpose in view, viz.: to give a continuous thread.

Getting the length of these stays is also quite an important matter. Taking a crown sheet with eight rows across and twenty rows long, the slope to be 5 inches in 10 feet, and assuming that each half would be alike; if crown sheet was marked on longitudinal center line then $8 \times 20 \div 2 = 80$ different lengths of stays. This is an amount which would cause much confusion and assorting.

To overcome this difficulty the wagon top and crown sheet are marked transversely into corresponding halves. A piece of ¼-inch square iron is then cut about a foot longer than the longest length, and a short lip bent over in opposite directions on each end, as shown at *M*, Fig. 13. Each end is then marked, as *B* and *F*, to distinguish between back and front. The bend is then lowered through the extreme back holes in first row, marked 1, 2, 3, 4, Fig. 11. The length of each is carefully marked with a scriber. An extra amount is added for driving, and the new lengths are permanently marked on the rod with a chisel. The rod is then turned end for end and lowered through the cross row marked *c-c*, Fig. 12, and each length is noted as before. This will make eight lengths, and if the stay is machine made, like *A*, Fig. 13, with about 3 inches of straight thread on the small end, eight lengths will be sufficient. When they are screwed to place they will assume lengths similar to *X-C-X*, Fig. 12.

The first bolt in the end row for each length will extend through just sufficient to drive. On account of the raise in the crown sheet, however, the ends will project through further

and further, till, when point *C* is reached, Fig. 12, the bottom end of the top thread will have nearly reached its margin of radius, and the front lengths will now commence to be put in. In measuring each length for the bolt maker it will be found that two, or sometimes three, lengths come within ¼ inch of each other. In this case we still have enough margin to discard the ¼-inch short lengths, and double the order for the next longest. As these lengths were taken from one-half the crown sheet, it will be necessary to double the number found for the other half, still making only six lengths for 160 stays.

Owing to several causes the top of back flue sheet often cracks from the flue hole into the rivet hole around the knuckle of the flange. As these cracks start from the water side they are not generally discovered until they make their presence known by blowing. If allowed to continue, they soon cause a honeycomb to form over the top rows of flues, thereby stopping them up, and rendering them useless as far as heating qualities are concerned. Sometimes they may be repaired by drilling along the cracked line, and screwing in plugs. Where there are several of these cracks radiating from one flue hole, and perhaps several flue holes in this condition, a more lasting job is secured by entirely cutting away the defective portion and patching, as shown at Fig. 14.

The rivets are first cut off and backed out. The defective portion is then marked to be cut out. Before cutting, however, it will be well to locate the lap and rivet line, as shown by the shaded portion, Fig. 4. The lap will cross several flue holes. These flues will then have to be removed. The holes are tapped out, and a steam-tight plug is screwed into each, just full flush. In the fire-box the plugs are made in sticks of three or four each, with a square on the end, to admit of a large wrench. The holes are all tapped the same size, and the first plug on the stick is fitted to one hole. The others are then turned to correspond, and are separated from each other by a niche of sufficient depth to allow of their being broken off easily, when the plug is screwed home. Both sides of the plug may now be riveted over, and the patch cut out.

Instead of plugging the corresponding flue holes in the front end, "short pockets" are used, which consist of a section of ordinary tubing, from 10 to 20 inches in length, with one end closed by pointing and welding. The other end is then tightened in position by rolling. After cutting out the old piece and scarfing, a strip of iron is bent to the radius of the crown sheet; also two short pieces are bent to the radius of the flange. A piece of steel plate is now trimmed to the size and flanged and bent to suit the templates.

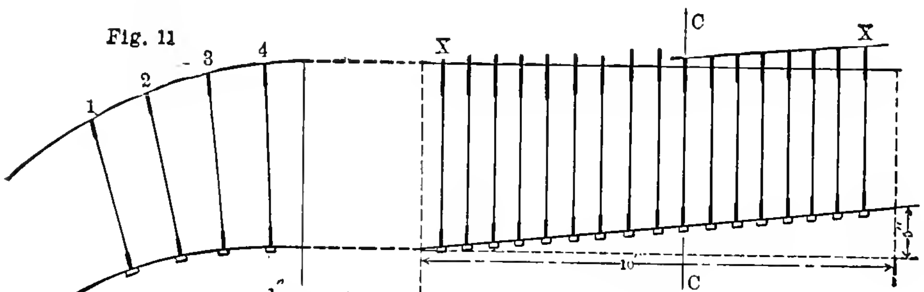


Fig. 11 Fig. 12

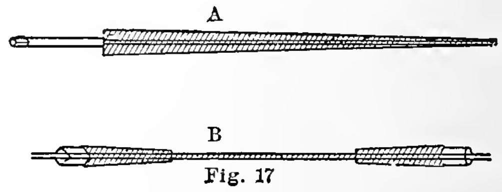


Fig. 17

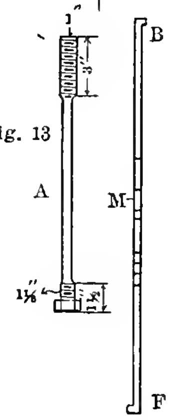


Fig. 13

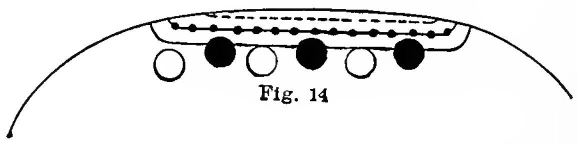


Fig. 14

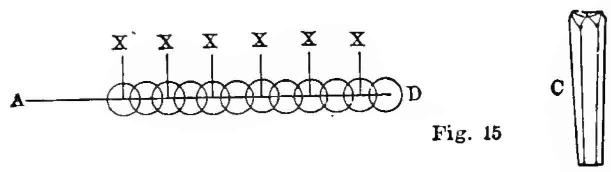


Fig. 15

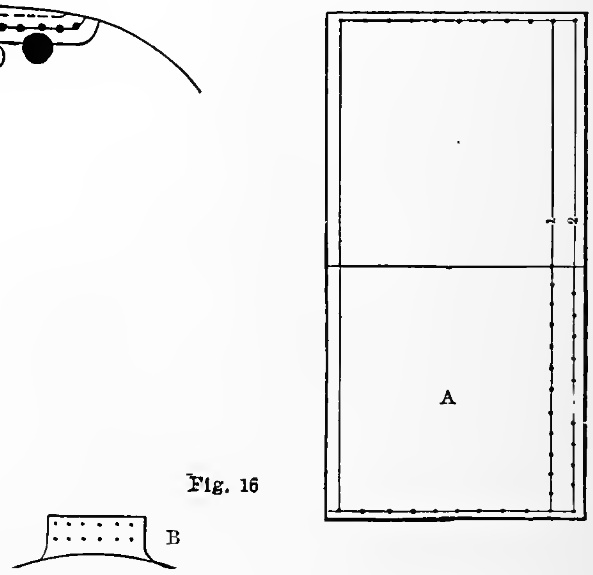


Fig. 16

Along the cut-out portion the flange should be cupped slightly, to enable the patch to lay up and more readily fill the space it is intended to occupy. Assuming that the necessary rivet holes have been spaced and drilled, the patch will be put in place and a few holes in one end marked. It is now heated, and unless it is a small patch, one end is fitted up at a time. As this patch is in an important place, and where small leaks play havoc with the upper flues, it will be good policy to take an additional heat, so as to make sure the patch fits snugly. The holes are now marked by scribing through the holes already drilled. The patch is then taken down, drilled and beveled for a calking edge on the emery wheel.

In this case we will put the patch in position with plugs.

To do so it will be necessary to put a bolt in every third or fourth hole, and draw up each one as much as it will stand. Then, after laying up edges of the patch again with a flogging hammer, tighten bolts as before. The reason of this extra work is that plugs having a continuous thread have no pulling power by themselves, so it is essential that there must be metal to metal before this operation is begun. After tapping out and screwing in the plugs they may be riveted over on each end. Then, instead of putting a fresh man to each plug, the edges may be cut in by applying a ½-inch rivet snap.

A patch of this kind is generally put on with rivets, and for the benefit of some who may think plugs would not have a sufficient holding power, this calculation is made. Assuming the patch to be 30 inches in length by 7 inches breadth around the flange, then $30-4=26$, $7-4=3$, $26 \times 3=78$ square inches exposed to pressure. At gauge pressure 200, $78 \times 200 = 15{,}600$ pounds, the magnitude of the force tending to dislocate the patch from the seat. To counteract this force we have forty ¾-inch plugs; the force necessary to pull or blow a ¾-inch plug through a ½-inch sheet is about 12,000 pounds. Then $40 \times 12{,}000 = 480{,}000$ pounds, the magnitude of the force tending to resist this pressure. Then $480{,}000 \div 15{,}600 = 30\ 3/39$; or, with a factor of safety of 6, showing the patch to be about five times stronger than necessary.

In the neighborhood of the fire line it very often happens that the sheet cracks around, and between the stay-bolt holes occasionally a bulge will start, and deflect the plate from a vertical plane an inch or more before being noticed. In that case it is customary, if the plate seems sound, to build a charcoal or coke fire on the spot, and force it back to its original position. The stay-bolts around the boundary edges are left in. To prevent the material from backing up beyond the defective zone they are afterwards cut out and replaced.

In plugging cracks between stay-bolt holes, or other places, recourse may be had to the method shown by illustration in Fig. 15, in which *A-D* represents the crack. Set a pair of dividers to spacing close enough to insure each plug a part of the space occupied by its neighbor. Step and center punch these distances from one end of the crack to the other. Now, in drilling, we will skip every other center mark from one end of the crack to the other, as *X X X X*. These holes may now be tapped out, and plugs screwed in; the remainder of the holes will now come between each two plugs, and if the dividers were set properly the drill, in going down between each two plugs, will cut about ⅛ inch off of each, thus drilling the plugs into one another. This method makes the job easier, and saves time over the other way of drilling and putting in each plug individually; for in this case half the drilling and half the plugging is completed in one operation, and the other half completed in the next.

After riveting over and chipping level, a straddle tool is used to smooth them up. Its shape is shown at *C*. It is easily made from a worn-out beading tool. After the leg is cut off it is concaved to the required size with a round file. If the edges of the plugs are cut in with a square-nose tool, this will make a very handsome job. It is perhaps unnecessary to add that the drilling must be done with a twist drill.

To locate and renew broken stay-bolts, where there is no regular inspector, the bolts are generally put in with the outside and drilled at least an inch in depth with a ⅛-inch drill, so that when the bolts break they will show up at the tell-tale hole. The fire-box is sometimes chalked off into divisions, and each division carefully sounded with a light hammer. The positively broken bolts can be made sure of by most boiler makers, but it takes much practice to locate the partly broken ones. For this reason some men will not rely on sound alone, but after chalking all that was found on the inside, will examine all the tell-tale holes in sight on the outside, and even get into the shell and look into the water spaces. Where all three methods are used in conjunction there can be but few broken bolts that escape detection.

It is customary in some places to cut the heads off all broken bolts in the fire-box, and then countersink the edges slightly with a chisel. The holes are now drilled outside, and the burrs removed. A long, keen half-round gauge is now driven between the bolt and the sheet on the outside, thus tending to draw the bolt sideways out of the hole. The inside counter-sink assists this action, and after the bolt is pulled over to the limit of the reach of the gauge, a small hand-offset tool will knock the bolt to the water space. In some cases, where the engine is not stripped, this method could not well be used. It is then customary to drill or cape the holes through both sheets in the ordinary way.

Where there are many bolts to be removed, there will generally be a few known as "blind," or steam-tight bolts, owing to the fact that they come behind the frame—pads—or other places where the outside cannot be seen. They are sometimes very difficult to put in. To remove a bolt of this description the inside is drilled first, and the broken bolt then knocked down into the water spaces. A wire lighter is then applied through the hole, to observe the condition of the outside burr. If the burr is level and even with the sheet, it is punched in the center and drilled through the water space. If the center is doubtful, or the bolt edges serrated, it will be necessary to take the drill down a few times to watch its progress. After being drilled the burr is removed with a water space gauge. This operation requires much skill, as care must be taken not to cut a groove in the outside sheet. Spindle taps are used to rechase the thread in both sheets.

In some places the stay-bolt is tapered on the end, to make a steam-tight fit; and again the inside sheet may be tapped slightly larger, and a straight bolt screwed to a steam-tight fit in the outside sheet. In both cases the projecting end in the fire-box is cut off and riveted over. In out-of-the-way places, where no suitable taps are to be had, an ordinary stay-bolt may be substituted for one by caping a few slots on the end, lengthwise of the body of the bolt, and afterwards dressing and tapering slightly with a file. The end is now heated and treated to a bath of potassium ferrocyanide, or, in other words, case hardened and cooled quickly. This process makes steel from iron for a depth of from 1/32 to 1/16 inch, according to treatment. This bolt may now be used as a tap.

This method, like filing a square hole with a round file, cutting left-hand threads with right-hand tools, and heating

a disc to make it smaller, is only a trick, yet at times quite handy. These may be classed by some as trade secrets. The writer has never seen them in print, and this will perhaps be the means of information for many.

At times the bottom of the shell at the girth seams on locomotives leak from various causes. Owing to the lagging and jacket covering the leak and keeping it moist external corrosion may take place, due to the aggravated conditions. Ordinary chipping and calking the seams will not be of much benefit if fitted badly. In that case a patch is riveted over the exposed surface. The rivet line is first marked along the shell on both courses. The girth rivets are then cut out, and the girth seams scarfed in length for a distance equal to the length of the patch. The scarfs are shaved extra thin at the laps, to allow of a close fit at the calking edge.

As an ordinary plate, rolled to either particular course, would not lay up to the adjoining sheet, it must be rolled offset. To do this, two strips of iron of the thickness of the required offset, are placed parallel, one on top and one on the bottom of the straight plate, and in passing through the rolls the sheet will be offset and rolled to the radius of the inner and outer courses. The sheet is then jacketed or bolted into place, and the girth rivet holes marked with a scriber. The other rivet holes may be laid out to suit the diameter of rivets used.

Before the patch is bolted to permanent position, the under surface of the shell, coming within the bounds of the patch, should be thoroughly cleaned and given a coating of red lead and boiled linseed oil. This will generally stop further pitting. The patch, after drilling, countersinking and beveling, may be bolted to place, and the remaining holes drilled in the shell. It is then riveted and calked.

The flues are first marked for length with a measuring

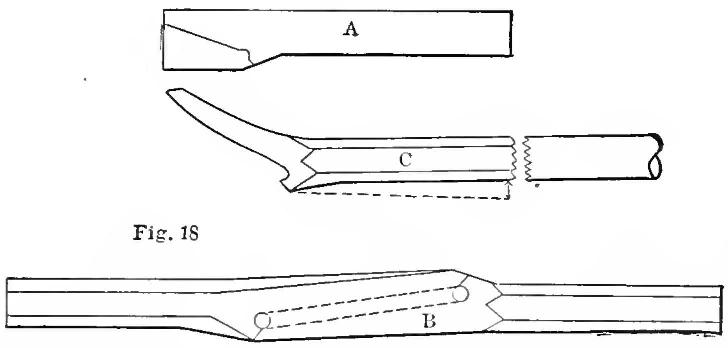


Fig. 18

pole, lengths are taken at each side, top, bottom and center If there is much variation each hole is measured individually, and its division marked on the bridge. Afterwards chalked circles are drawn around the areas, including measurements of the same length. When the flues are cut off, annealed, swedged and brought over to be put in, each flue bears a distinguishing mark, in order to locate it in its alloted section. In working the fire-box end, while the flues are being welded, it is customary to roll coppers in all the flue holes. One safe end then of several sizes, gauged by numbers, will be found to average up among all the holes into a snug fit. The flues are then swaged to this size.

In setting flues in the shell, if there are any new ones, they are put behind the steam pipe. A boy or man working in the barrel will take the flues in through the big hole, and transfer them to the sides, till steam pipes and door are in clear. Then each flue may be entered in its own hole. For beading length in the fire-box the rule is to allow 1/16 inch for projection for every inch of diameter of flue. After the flues are in, a man in the front end places a suitable pin in each flue, and drives it back to suit the judgment of the boiler maker in the fire-box, who then clinches it in position by turning a lip down on one side. After all the flues are worked in this manner they are known as set.

It is next in order to expand and bead, where rollers and expanders are both used, or prossers. It is then a matter of judgment for the operator to decide the proper amount of working for each tool. The flues are then turned over or belled out and beaded. Beading tools on a well regulated system are filed to a standard gauge for both back shop and round-house work.

As beading tools are the hardest to make of all the boiler makers' hand-tools, a few words as to their forging may not be out of place. A piece of ¾-inch hexagonal or octagonal steel is cut to the desired length. The end is then heated and upset about 1½ inches from the point, enough to form stock for the heel. It is then flattened and cut, as shown at Fig 18-A. Another mode of making two at once is shown at Fig. 18-B. The length is made twice as great as before, upset in the middle, and flattened to the desired thickness. Two 5/16-inch holes are machine punched in the metal while hot, on opposite sides, as shown. The cut is then made with a hot chisel on dotted lines, as shown. They are then bent slightly and swaged or filed rounding.

Boiler makers used to (and do yet in some small contract shops) make their own tools. Therefore, it is well to be prepared for an emergency, and, as in this instance, be prepared to meet it.

In replacing the stock, the inside measure of the base is taken and the sheet stretch-out is squared up as shown in Fig. 16-A. The ends are butted and riveted with inside strap. The only trouble likely to arise is getting the base rivet holes in flat sheet. It may be done by stripping them off on a piece of square iron the same thickness as the stack, and marking their center on lines 1-2, as shown. Care must be taken not to turn the strip around after marking, or the holes will not match when sheet is rolled.

CHAPTER IV.

FIRE ENGINE—STATIONARY.

Stationary boilers may be divided into two general classes, known as water-tube and fire-tube. These again are subdivided into classes of their own. As the general principles for which they are constructed in all cases remain the same, no further classifications will be made.

Taking the two-flue boiler of forty years ago, shown in Fig. 19-A, simplicity of construction is its distinguishing feature. What few of them remain in use at this date are not liable to tax the skill of an ordinary boiler maker. The only operation likely to cause trouble is the removal of the flues, and holding on the rivets when the flues are again in place. The flues

themselves may be made of telescopic plate sections, or inside and outside courses riveted together, as shown in Fig. 19-B. In either case one end is always belled or tapered to fit the large hole generally located in the back. When the rivets are cut out of both ends and the flue blocked up at its small end, to keep it from dropping to the bottom of the shell too soon, the flue is pulled out of its own hole, large end first. After the first section is in the clear, the rest of the flue will generally pass without any further trouble.

Assuming that the necessary repairs have been made, and the flues are ready to be put in place, one flue is first put in and riveted up complete, the extra room gained that would be taken up by the other flue, being enough to warrant this plan. When the other flue is put in place there will be some of the rivets on the sides and bottom very hard to hold without special tools. For this purpose "spoon bars" are sometimes used. They are made from a piece of wrought-bar iron, short enough to handle crossways in the shell, and offset enough to conform slightly to the curve of the flue. Leverage is obtained by using a hook bolt in a hole several spaces in advance of the rivet to be driven. These rivets may also be held with a chain having one or two especially prepared links. One end of the chain may be fastened to an overhead brace by lapping with and adjustable hook. The solid link is set to catch the rivet head; the other end of the chain is brought around the flue and fastened to a bar with an S hook. A piece of iron laid crossways over the flues will now make a fulcrum, and with the bar acting as a lever any reasonable pressure desired may be brought to bear on the rivet head.

The 6-inch flue boiler shown in Fig. 20 is but slightly different from the boiler shown in Fig. 19. In this case there are twelve flues 6 inches in diameter, and riveted to the shell as before. On account of the very small space in a 6-inch flue in which to guide a hammer, especially made hammers are used for this purpose, in which either the eye or the handle is put in crooked, and the face bevelled to suit. As the head holes are flanged inwardly to suit the diameter of the flue, these flues are not beaded, but may be split-calked with a fine tool.

In boilers of this description, where the dome meets the shell, the enclosed material is not often cut away, but simply perforated enough to allow the free passage of steam. In that case, if the dome head has to be removed, the rivet heads cannot be held by a man on the inside. It will then be necessary to cut a bar of iron of the length of the internal diameter of the head, minus the thickness of two rivet heads.

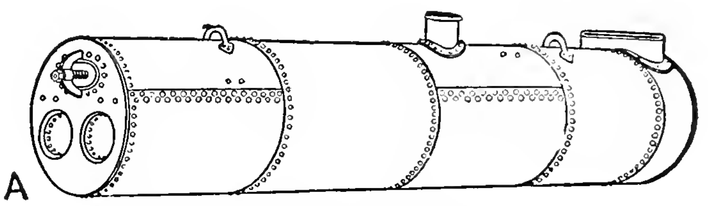
This bar is then drilled in the center (cross-section) and suspended through the "nigger head" hole. When the hot rivet is in place, one end of the bar is applied to the head. The free end is then swung to either side until it meets the shell, and is then held in place by applying a bar to any of the holes that may be in line.

An upright submerged flue boiler is shown in Fig. 21. Where they are offset at the bottom to meet the outside shell, as shown, scale and sediment settling on the inside have a tendency to keep the water away from the sheet, thereby sometimes causing a bulge or pocket. Again, the corrosive effects of sulphuric acid, which may be generated from wet ashes, will sometimes cause a general pitting around the bottom on the fire side. Both of these destructive agents working in unison will sometimes cause the bottom to give out long before the fire-box proper would need replacing under ordinary conditions.

In that case, if the rest of the fire-box and flues are in good condition, the defective portion alone may be cut out to just clear the first row of stay-bolts (as shown by dotted line); and an ordinary mud-ring made of wrought iron of a thickness to correspond with the depth of the water space may be rolled and welded, and placed in position. It will not be necessary to cut away any of the outside shell, as the mud-ring may be readily calked in its new position.

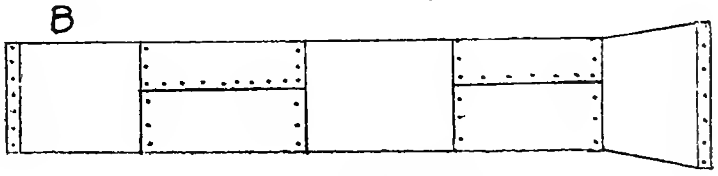
If a new fire-box is needed, however, the flues are first removed and the rivets and stay-bolts next cut out. After the

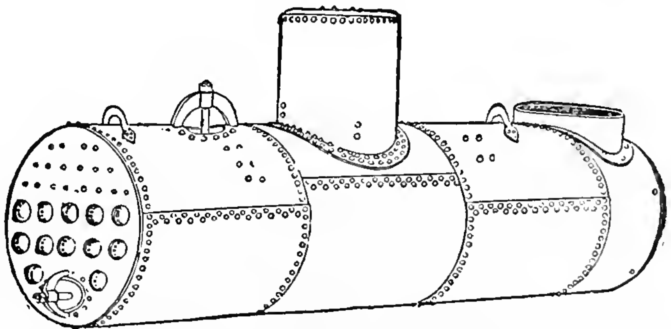
A



The Two Flue Boiler.—
FIG. 19.

B





The Six Inch Flue Boiler.
FIG. 20.

box is removed and the size is taken, the flue sheet is first laid out and flanged. It may then be wheeled and retraced on the stretch-out of the envelope, and an extra amount added equal to three and one-quarter times the thickness of the metal used. The width may be found by adding one-half the depth of the water space to the perpendicular height, as shown. The stay-bolt holes may be stripped off and transferred to the sheet; also the side seams are laid out to correspond, and the flue sheet rivet holes marked and punched to match. The sheet is then rolled and riveted, and the bottom is flanged to the inside diameter of the shell. The mud-ring rivet holes are then laid out, punched, and the box riveted to position.

In replacing the flues there will be a number of the ends in the water jacket that come so close to the tapered connection that they cannot be rolled at this end with a common roller. In that case the cage with the enclosed rollers alone are set in this end, and a long, tapered pin is worked through the flue

in the fire-box end. It is either square on the projecting end or has a few holes punched in its cross-section at an angle with each other, to allow the use of a lever pin. The rod is driven in until the rollers have a good grip. They are then turned and redriven until the flue is rolled sufficiently.

A common make of a city fire engine boiler is shown in plan and section in Fig. 23-A and B. Owing to the rapid steaming qualities essential to its use, it differs in many respects from all of the boilers previously described. The general principles of its construction are to separate the enclosed volume of water into small and communicating masses, by means of tubes and drop flues. A large area of heating surface is obtained, on account of the number of the drop pockets and tubes. Owing to their peculiar construction and rough usage when in service, they require especial attention, and much care is exercised in their washing.

As shown in Plan B, Fig. 23, which is a plan view of the top flue sheet, the flue centers are arranged in concentric circles, the outside rows being 1¾ inches diameter, gradually reducing to 1 inch in the center. In the fire-box shown in section, Fig. 23-A, the flue bridges themselves are drilled and tapped out to receive a hollow section of piping closing to a square at the bottom end. They are arranged in lengths radially, as shown, to conform to the bed of coals. These pipes inclose a section of galvanized or copper tubing of a size equal to about two-thirds of their own internal diameter. These are split and opened out at their bottom end to allow a free circulation of the water, and to keep the upward and downward currents from interfering with one another. An enlarged view of one of these drop flues, with the piping in position, is shown at *C*.

In case of repairs, the tubes, pockets and tools being of such an odd size, are generally furnished by the builders. The pockets will generally be the first to play out, as they collect much sediment and cannot be emptied of either mud or water without turning the boiler over. In running to or from a fire the vibration acting on these pockets sometimes causes them to eat through the threads and leak next to the flue sheet. As the spaces between them are so small it is generally a difficult matter to tell which one is doing the leaking. It may sometimes be necessary to unscrew and take out several before the right one is found. The defective part may then be cut off and the pocket rethreaded and again applied. If too weak to stand cutting, a new pocket or plug will have to be applied, with a socket wrench.

If a full new set of tubes and pockets is needed, the boiler is run into the shop under an overhead beam. The front wheel trucks are disconnected and the boiler swung to a horizontal position with a block and tackle. After the pockets are taken out the flues are removed by grubbing with a steel bar. This action is accomplished by cutting the flues loose on the inside of the sheet with a tool like a cape chisel bar bent over squarely. The burrs are afterwards cut out, and removed through one of the large outside holes, care being taken not to allow any of them to drop into the water space. As the mud-ring is made of from ⅞ to 1½ x 3-inch bar iron, bent flat-ways, it leaves a very small water space, and any foreign matter like burrs, nuts and washers is sometimes hard to fish out.

As these flues and tubes are worked like the ordinary kind we will now turn our attention to the self-contained oil-field type of boiler, shown in Fig. 24. It being a modification of the locomotive. It possesses many advantages over all other types of boilers for this especial purpose. Where first cost, free steaming qualities and ease of transportation are essential it has won out over all other competing makes. They are built in sizes ranging from 30 to 50 horsepower, with shells from ¼ to 5/16-inch steel. Instead of a cast or wrought mud-ring the bottom is enclosed by a flanged shoe turned inwardly on all four sides. On account of the lightness of the plates the steam pressure is rarely allowed to go above 110 pounds. They contain from forty-five to sixty 3-inch flues, ranging in length from 7 to 14 feet.

By far the most expensive item in the repairs of these boilers is the flue maintenance. In oil field districts, where the water sometimes runs over 60 grains of impurities to the gallon, the flues will last but a short time. As a new set costs between $100 and $200, various ingenious methods have been devised to reduce their cost rating to a minimum. Perhaps the most general practice is to weld 6-inch new ends on the old flues cut to the required length, and again apply to the boiler. Also at times a long old flue is swaged to the internal diameter of the fire-box ends, and cut to lengths of about 1¼ inches. Half of the old flues are now removed in vertical rows by skipping every other flue. The remaining flues in position are cleaned as well as possible and expanded in the back end. The beads are cut off level and the 1¼-inch ends driven tightly up to beading length, then rolled, turned over and beaded. The other half are then welded and replaced, or else put in new out and out, thus keeping half a set of flues on hand all the time. In the next case of retubing the bushed ends are removed, and the other tubes worked vice versa. This method, while appealing to the penurious, is not advocated by the writer, and if used at all should be done only in isolated places, and in cases where the low pressure would warrant safety.

Where the tubes range in length over 9 feet they are sometimes cut off flush in the fire-box and front end, and are ripped just enough for them to drop down and pull out at the front hand-hole plate. The rivets are then cut out of the front flue sheet, and the edge of the sheet corresponding with the lap is jerked out enough to allow the seam to be scarfed back about 4 inches. Two rivets are then cut out of the lap, and the back one redriven, countersunk on the inside. The flue sheet is then moved back to this space, the shell marked and drilled, and the flue sheet riveted in position. The old flues may now be cut off to this length, cleaned and annealed, and applied as before, care being taken to reverse them before setting. The blank holes in the smoke-box may now be closed with either bolts or rivets. After the sheet has been moved back several times new ends are welded on the flues, and the flue sheet is riveted in its original position.

In this type of boiler the fire-box is generally made in one continuous sheet, having a flat crown sheet supported by

driven stays. It frequently occurs that the crown sheet bulges or drops and may pull loose from three to four stays. After heating and straightening the stays are counted and located on the outside. Generally they will come somewhere under the dome. A hand-hole is then cut, as shown at *H*. If it is a through stay which is riveted on the outside of the dome cap, as shown by dotted lines 1-2-3, they may be easily replaced; but if, as is generally the case, the wagon top is not cut away under the dome, but simply perforated slightly, most of them will be found riveted into a reinforcement plate on the wagon top, in which case they are very hard to get at, and it does not pay to remove them.

The bottom end is then pried away from the hole, and a long drill inserted through the crown sheet. On account of the curvature of the shell the drill may have to be set at an angle with the crown sheet, to keep it from walking, but in no case should this angle exceed 30 degrees. If a rivet hole in the dome flange is found to come within this margin, it may be tapped out and a hollow middle stay used. After the hole is drilled, it may be found that there is not enough space to use a spindle tap. A piece of round iron, small enough to go through the hole, is then threaded and welded to a stay-bolt, as shown at *M*. That makes a steam-tight fit in the crown sheet. Two nuts and washers are then screwed on the other end of the bolt, one above and one below the wagon top. The one coming below the wagon top may be fished into position through the back head hand-hole plate, or strung through a steam passage hole in the wagon top. As the holding power in the thread of a ¼-inch sheet is insufficient to allow the bolt to be driven while held by its own tenacity, it will be necessary to use an offset bar through the hand-hole while the bolt is being riveted on the crown sheet.

Sometimes the crown sheet strips the bolts in its entire length, and drops too far to straighten. It will then be necessary to replace with a new one. Before cutting out, however, it will be best to measure the space in the clear between the mud-ring shoes, and mark the crown sheet to cut accordingly. As this will seldom take in all the warped material, the sides and flanges will have to be straightened. The new sheet is then gotten out and placed in position by tilting the boiler until the bottom is open enough to allow the sheet to pass and enter the steam chamber. The side seams are marked, and the crown plate pushed back on the flues. Then these holes are either screw punched or drilled.

In order to more readily hold on the rivets four hand-holes are cut in the sides, their bottom coming on the dotted line representing the level of the crown sheet, shown in Fig. 24-A. Most of these boilers are equipped by the builders with a hand-hole in the back head. In case the boiler in question has none, it will be well to examine the arrangements of the braces in the back and before cutting one in. Very often the rows of T-irons will not allow a hand-hole to be cut above the crown sheet. In that case it may be left out, and an additional one cut in the sides. The sheet is then bolted to place, the hot rivets are applied with a spring tongs, and the head is held with a semi-circular ended bar small enough to enter the hand holes. The projecting position is measured for height from the floor, and a plank cut to suit. When the rivet and bar are in place, the plank slipped under the end will keep a heavier and steadier strain on the bar than if held in position by main strength. The rivets are driven overhead unless the boiler can be turned easily. Like all other work subject to the flames of oil, the lap and rivets are left as scant as possible.

Very often these boilers are made with a sheet or water bottom, and a round fire-door and crown sheet. In that case the last mentioned method will not apply. If the crown strip is not much wider than the door it may be bent enough to squeeze through and afterwards straightened. Some manufacturers place their longitudinal seam on the top or quarter at the back end. This seam may then be ripped open enough to

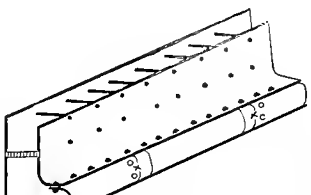


Fig. 25

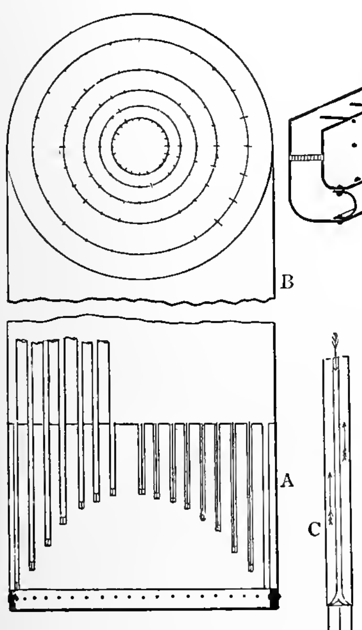


Fig. 23

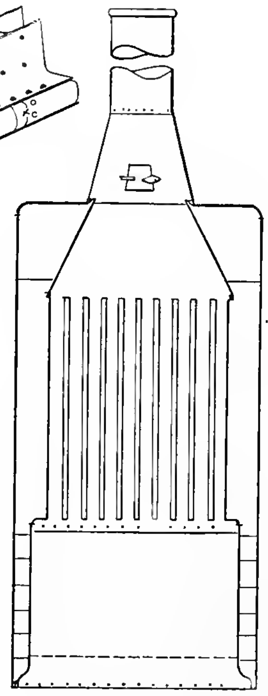


Fig. 21

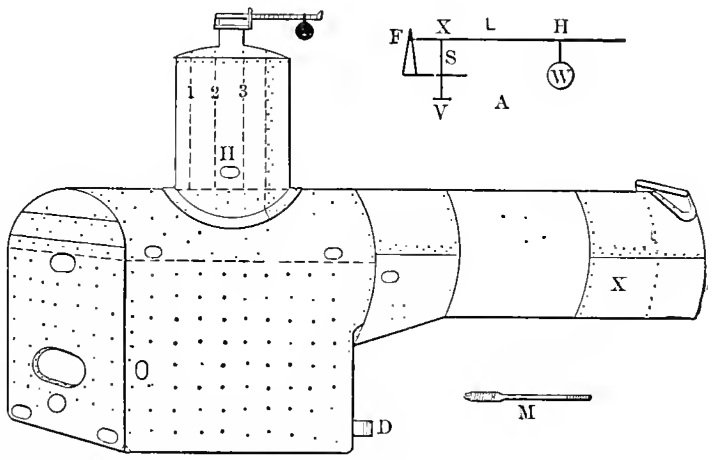


Fig. 24

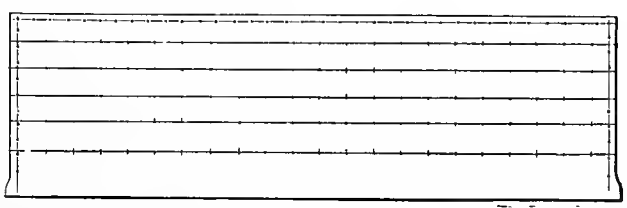


Fig. 22

allow the old and new sheets to be transferred, and again riveted before the crown plate is bolted down. If there is no seam handy a rip may be made in the solid plate and afterwards closed with an inside and outside butt strap. The varying conditions will, of course, govern the method to be used. If the flues are worn out, it will, of course, be cheaper to remove them, also the front flue sheet, and apply the crown sheet by way of the front end.

As most of these boilers blow off and feed through the pipe in the bottom of the throat sheet marked *D*, it keeps the sediment in the shoe banked against the sides of the curved ring, thereby sometimes causing a burn or bulge as shown at Fig. 25. The burnt portion is removed, and a slip patch properly applied has been found to give good results. The defective portion is first marked and cut to clear the rivets, as shown at *X-X*, about 2 inches. On the inside of this cut at each end make a parallel cut to enclose the U-shaped piece of metal which is in view from the outside. When these two pieces are removed the inclosed inside portion may be cut out with the same tools, without raising the lap. A flat sheet is then laid out to form the U-bend, and an amount added at each end for lap. The four corners are then scarfed and the sheet bent to shape. After heating and fitting to position the holes are marked through the shell, and two additional holes are put in each end to catch the old flange.

In this type of boiler there is always a hand-hole plate at each of the four corners directly in line with the rows of rivets. It is not large enough, however, to allow a full-size wedge bar to be used in holding on the rivets. In that case a cup is worked through the hand-hole in the other end, of a sufficient thickness to allow the wedge to drive several inches. In getting the four holes in the curved portion it will be necessary to either block up under the wedge with strips of wood or iron, or else insert plugs or patch bolts. When these boilers are patched on the shoe, it is good practice to raise the fire line above the patch, and also disconnect the feed from the throat sheet, and locate it in the front ring about 22 inches from the flue sheet, as shown at *X*, Fig. 24.

The writer has known cases where the boiler had sheet down on account of leaks, and on changing the feed in this manner to give no further trouble for months afterwards. Strangely, occasionally two boilers, apparently exactly alike in detail, and working under the same conditions side by side, will give results entirely unlike. In that case experimenting with the burners will sometimes eliminate the trouble; usually there is a short flue expanded into both sheets below the fire-door, as shown. In this tube the spray burner is set and pointed at a target made of brick checker work. This target splits the flame and keeps the direct action of the fire from impinging on the flues, as the sides catch the brunt of this intense heat, varying around 3 000 degrees F. It causes very violent local ebullition, and if the water space does not admit of free circution there is liable to be priming, and occasionally sharp reports are heard, as if the boiler had been hit with a hammer, thus indicating that the boiler is working under very unsatisfactory conditions.

Experiments have shown that when the burner is placed beneath the throat sheet and pointed at the door, the oil globules mixed with dry steam spray will form a rolling flame that acts on all the heating surface of the fire-box at once, thus causing each part to contribute its own pro rata to the general efficiency of the boiler. This last mentioned method of firing will often do much toward overcoming the defects in an ill behaved steam generator.

Perhaps one reason why this method of firing is not in more general use is because it has been noticed on certain types of boilers with a wide back head that the sheet has deflected from the perpendicular around the door, by an amount varying from 1 to 4 inches. Under the head of repairs the writer has no solution to offer for this problem that would justify the cost. Perhaps the best service for a boiler in this condition, that has to be directly fired, is water heating. Even then a sentinel valve should be placed on the boiler, and set to screech at a few pounds below the operating pressure of the safety valve.

In setting the safety valve the lever is generally graduated and stamped for the different pressures. In case it is not, the weight may be easily set, providing the principles involved are understood. Referring to the skeleton diagram in Fig. 24-A, *F* is the fulcrum, *L* the lever, *W* the weight, *S* the stem, *V* the valve.

In calculations pertaining to the lever safety valve there are five things to be determined, and it is necessary to know four of these in order to find the fifth. They are the weight of the ball, the area of the valve, the fulcrum, the steam pressure, and the length of the lever. In this case the length of the lever is to be determined, to know where to set the ball. Assume the following data: Weight of ball, 10 pounds; area of valve, 3 square inches; fulcrum distance, 3 inches, and steam pressure to be 25 pounds.

It is obvious that the area of the valve in square inches, multiplied by the steam pressure in pounds, will be the magnitude of the internal force, or $3 \times 25 = 75$ pounds. It may then be readily understood that if a 75-pound weight be placed at the point *X*, the forces will be in equilibrium. Then if moved to the point *H*, which is five times the distance *F-X*, it will take $5 \times 75 = 375$ pounds pressure to raise the valve. Therefore, a much smaller weight may be used. There is also a small amount to be subtracted from the total upward force, due to the weight of the valve, stem and lever, which may be found by calculation, or with a spring scales; in this case 15 pounds.

From the foregoing data the following formula is deduced:

$$D = \frac{V \times P - W^1}{W} \times F, \text{ or } \frac{3 \times 25 - 15}{10} \times 3 = 18$$

inches distance for the ball to be set to pop at 25 pounds pressure

If the length of the lever is given and the weight of the ball which will counterbalance a certain steam pressure is desired, the above formula must be solved for *W* instead of *D*.

Having discussed the methods of making all usual repairs which are necessary upon locomotive and stationary firetube boilers, we will next take up the question of repairing water-tube boilers.

CHAPTER V.

A popular form of boiler used in the United States and Europe is known as the water tube. This name is applied to a class of boilers that contain water in stacks or nests of tubes of small diameter, which communicate with each other and with a common steam and water chamber. The products of combustion circulate around the tubes, and are usually guided to their exit by baffle plates. There are many varieties of this type of boiler in use; however, they differ from each other in detail rather than in principle of construction.

An early type of water-tube boiler is shown in Fig. 26. Like all other boilers of the water-tube variety the principal item of repairs is tube renewal. Owing to the bottom row being more fully exposed to the action of radiant heat, they will be the first to give trouble. Expanding alone will not always stop the leak, as in this case the steam pressure has a tendency to tighten the flue, and when leaking begins it is often caused by the flue being eaten through at the header.

In renewing a tube in the bottom row, the corresponding front and back header caps are removed, as shown at *H-H*. A

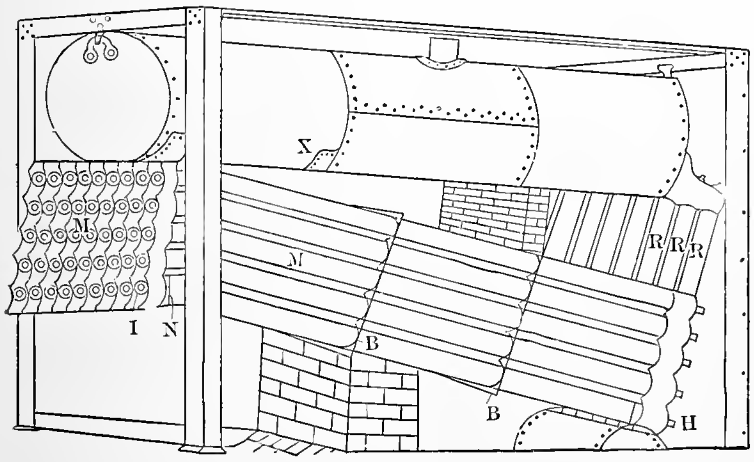


FIG. 26.

section of the baffle plate is then cut loose at *B-B*. The tube may now be cut loose at each header with a three-wheel pipe cutter, or a ripper or chisel bar, as shown by dotted lines *N*. After dropping in the clear, the old section may be pulled out through the door. The burrs are then gouged out, and the bearing surface of the header cleaned with a fine file. After the new tube is set in position the surplus is divided evenly for length in each end, and if necessary an iron or copper shim is added to make a tighter fit in the hole, care being taken to scarf each end of the shim, and see that none of them are made of galvanized iron.

A peculiar form of expander is used to tighten flues on most water-tube boilers. For this especial boiler an expander with an adjustable slip collar small enough to enter the header is used. There is also an extra pin furnished, with a link combination that makes an almost universal knuckle. This pin is used in combination with the roller cage for tightening the bottom ends of the riser tubes shown at *R-R-R*.

After the expander is in place, it is manipulated in the same manner as in the case of a fire-tube boiler.

In the case of tubes leaking among the central rows, as at *M-M*, it is sometimes difficult to locate the exact one. After locating it as nearly as possible, however, all the tubes in the immediate vicinity are also rolled. If that does not stop the leak, it is customary to locate the leak from inside of the furnace, while the boiler is filling with cold water.

In taking out a tube above the first row, the header caps are first removed, and the tube is then split and closed in at each end, care being taken not to scar the header. If the building in which the boiler is situated has space enough between the boiler front and the wall to allow the flue to come out the front way, it may be easily replaced. If, however, as is often the case, it must go out the back way, on account of the elevation of the boiler at the front end, the tube end, coming out as it does at an angle, will often strike the ground before the other end has cleared the water space. It will then be necessary to dig a trench, or bend the tube to suit the case.

In moving this type of boiler from place to place, each nest of tubes is left in its own header, and the front and back

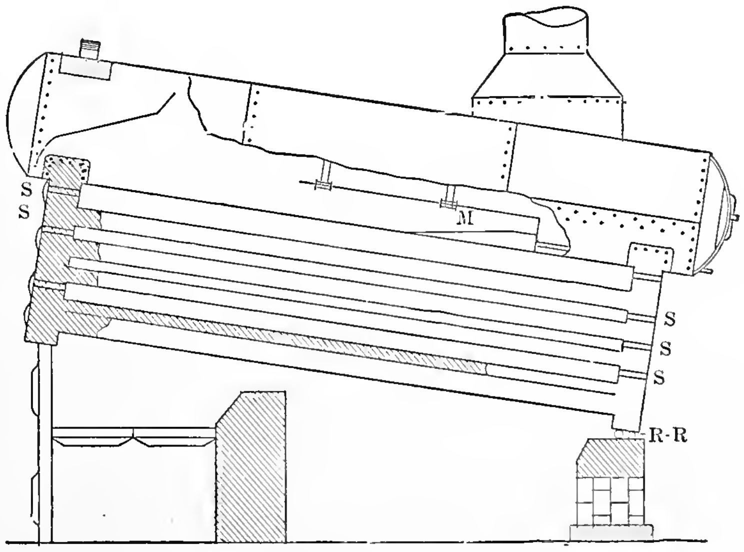


FIG. 27.

risers alone are cut loose. After the boiler is again set up, new risers are cut to the required length, and tightened to a steam fit with the link pin previously mentioned.

Owing to various causes, the bottom of the steam drum sometimes corrodes, and gets quite thin near the seam, as shown at *X*. A slip patch may then be applied by first cutting the rivets loose and then raising the seam with a couple of lap wedges. A piece of boiler steel is then cut to the required dimensions, and scarfed back a few inches to a feather edge. It is then rolled to the drum radius, and the thin edge is driven home in the crescent opened by the lap wedges. The holes are then marked and the patch taken down and drilled. The seam holes may be moved outward slightly to allow for draw.

After the bearing surface of the drum is well cleaned, it is good policy to coat it with some non-corrosive adhesive mixture, such as cement or red lead and oil. The patch is then again put in place, and bolted up through the draw holes. The body holes in the drum may then be drilled through the patch in position; the riveting and calking may then be done as previously explained.

The Heine water-tube boiler shown in Fig. 27 differs in

many respects from that shown in Fig. 26. The mud collector is located in the steam drum, as shown at *M*. The water legs are strengthened with hollow stays, as *S-S-S*, and the back water leg rests on rollers at *R-R*. As the deviation from the horizontal in this boiler is small, the tubes may be readily renewed. After cutting out, as in the previous case, an ordinary fire-tube expander may be used on this type of boiler, providing the guard has been removed, and an extension fitted to the mandrel pin.

In isolated places, when a tube gives out and none are at hand, a temporary repair may be made by swaging a short

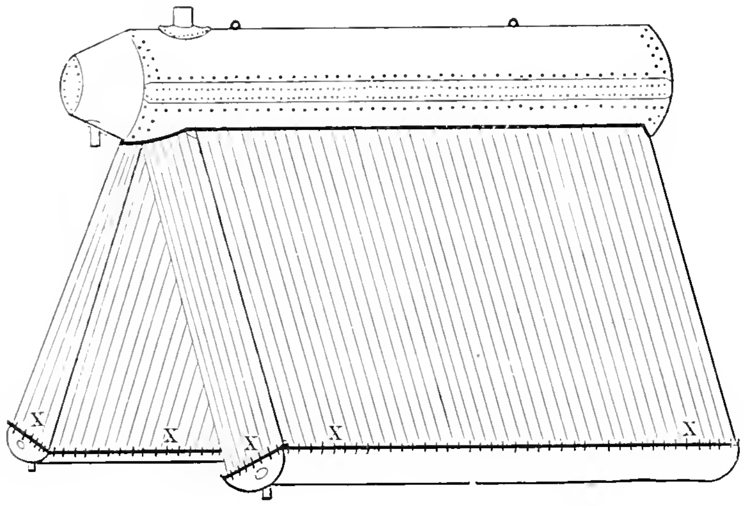


FIG. 29.

plied, and if handled properly will do the next best thing to a permanent job.

A peculiar shaped, but very efficient, type of steam generator, is shown in Fig. 28. It is known as the Stirling water-tube boiler, and consists of three upper steam and water chambers, and one lower large drum, all connected by stacks of nearly vertical 3¼-inch tubes, as shown in the end view. The hot gases strike the first row of tubes near the bottom, and are guided by a partition throughout their length to the top, where they cross over and strike the second stack of tubes at *C*, thence ranging downwards to the bottom drum, and up the last stack of tubes to the atmosphere.

The circulation of the water is rapid and positive, and takes place as follows: The hot water, with the steam bubbles in entrainment rise through the two front stack of tubes, and descend in the rear. The top back drum delivers the feed water downwards through the back nest of tubes.

The tubes themselves being of an odd shape and size, extra ones are generally furnished by the builders. In replacing old tubes, they are first ripped and closed in at each end from inside the drums. The end is then knocked out of the top hole until it is clear of the bottom of the drum. It may then be turned enough to start through one of the side doors in the boiler front. Where the proper expander is at hand, no trouble will be experienced in resetting the tubes. When two men do the work, the tubes are first assorted into groups of

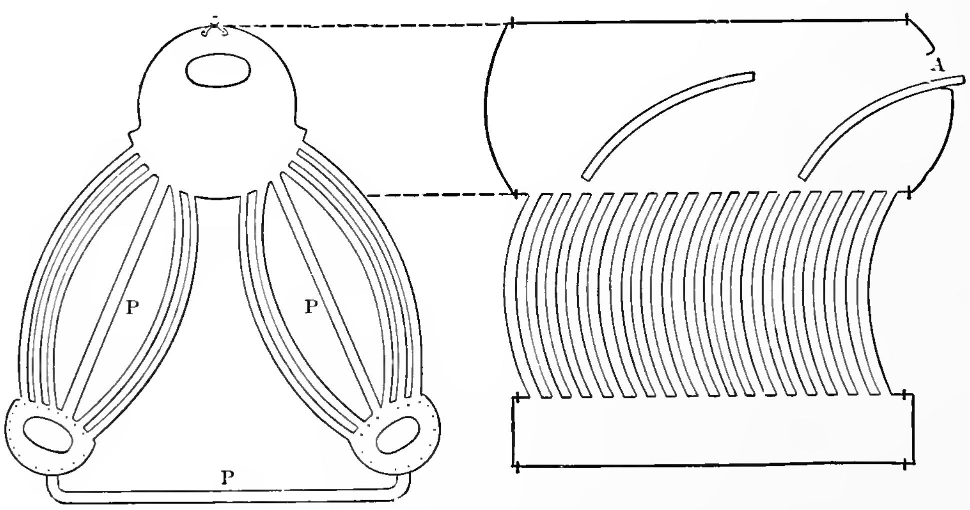


FIG. 30.

section of tube or piping to a little more than the internal diameter of the tube. From 4 to 6 inches may then be cut off and split in a longitudinal direction. The split edges are then draw filed, giving the corresponding end of each about a 1 to 8 taper. The two pieces may have to be tried in the hole several times to form a nice fit. A distance piece is then set in the split bushing, to keep the bearing edges from turning in. It is obvious, then, that if the end of one of the sections be driven in with a bar, the taper will cause the bushing to make a snug fit in the tube end.

To make a more lasting job, a piece of No. 8 or 16 gauge iron, 1½ inches wide, is cut to a length equal to the inner circumference of the bushing. A pair of roller tube expanders of the next size below the original tube may then be applied...

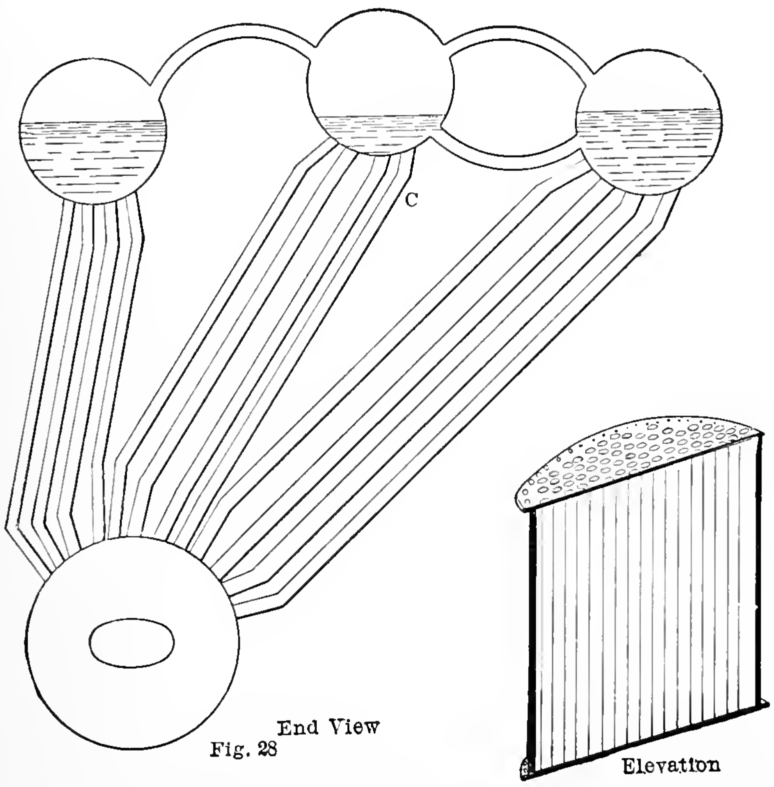
the same length for each row. Marking the top end of each, as the bottom and top are curved to a different radius, the bottom end of the tubes may now be marked about ⅞ inch from the end, this mark serving as a guide for the man holding up the tube in position. When the mark is at the edge of the hole in the bottom drum, the other man, working from inside the top drum, will then clinch the flue in position, provided the lengths are running even.

In replacing from one to six scattered tubes, it often happens that the shop doing the work has on hand for the next nearest size a 3-inch Dudgeon roller only. In case of compulsion, they may be used, by cutting a 3-inch tube into 1½-inch sections, and driving one section in each end of the tube until its center is in the same plane as the tube plate. The

bushing may then be rolled out until the enveloping tube is a steam-tight fit.

A section side view of the Yarrow marine water-tube boiler is shown in Fig. 29. As illustrated, it roughly resembles an inverted V. The furnace is placed between the legs, thus imparting heat to the tubes and water by conduction and radiation. The products of combustion flow between and around the tubes, and the convection currents of water ascend the inner rows, as shown at *X-X-X-X*. The bottom tube plates connect with a semi-cylindrical drum or water chamber.

The drum not being of sufficient size to accommodate a man, the tubes may be renewed by first disconnecting the chamber body from the tube plate, and then cutting the tube ends loose in one of several ways. They may be sheared off at the top of the bottom tube plate, and ripped and closed in at the top, or ripped or sheared top and bottom; or cut at top or bottom and pulled out of the opposite hole through the furnace.



End View
Fig. 28

Elevation

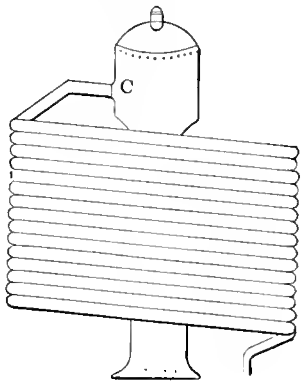


Fig. 32

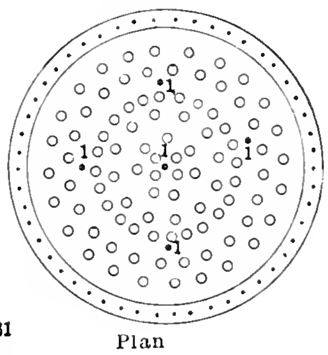


Fig. 31 Plan

In resetting the new tubes, the bottom tube plate, being loose, must be set in position by blocking or by leaving in a sufficient number of old tubes to sustain its weight. Again, a few new tubes may be divided throughout its length and rolled in place.

The "hog-back" boiler, shown in Fig. 30, is built on the Yarrow principle, but embodies several distinguishing features, chief of which are ease of access to the tube ends, and construction lending to the ready renewal of same. As shown, each water chamber is provided with a manhole, thus enabling the bottom tube ends to be rolled without inconvenience. Referring to side view, it will be seen that the curvature of the tubes allows them to be readily withdrawn through the manhole located in the back of the steam chamber at *A*. Any individual tube may thus be cleaned, examined or renewed without difficulty.

In renewing a full set, the large circulating pipes *P-P-P* will sustain the weight of the water chamber without additional blocking. These two last named boilers are of European make, and are used to a certain extent in foreign navies. They are built in sizes ranging from 500 to 1,800 horse-power.

A cylindrical type of automobile boiler is shown in Fig. 31, plan and elevation. The tubes are of copper, and of small diameter. They are spaced in rows corresponding to concentric circles, as shown in plan. Being in reality a fire-tube boiler, the tubes may be grubbed or ripped out, as explained in a previous issue.

In tightening the ends of new tubes, a tempered steel pin of small taper may be driven in each to suit the judgment of the operator. A segment collar is then set in the tube, just clear of the inner surface of the tube sheet. A drift pin is then driven into the collar, thus opening it and enlarging the tube so that when linear expansion takes place on account of heat when the boiler is in service the tendency will be for the tube to become tighter in the sheet. Through and through stay-rods are sometimes placed between the bridges, as shown at *I-I-I-I*. In case of renewal they may be drilled out and replaced in the same manner as an ordinary stay-bolt.

The outside shell of the boiler proper is wrapped with bands of ribbon steel, or they are sometimes reinforced with strands of piano wire. These last mentioned details are factors in the cause of safety, and are used as a precautionary measure to insure freedom from explosion.

Fig. 32 represents a type of boiler known as the nest-coil semi-flash. It consists of a coil of ¾-inch seamless tubing, ranging in length from 30 to 60 feet. The feed-water is delivered into one end of the coil at the bottom, in very small jets, at varying intervals. It is almost instantly flashed into steam, and in traveling through the length of the coil it is further heated and delivers into the small drum *C*, in the form of superheated steam.

Strictly speaking, this not being much of a boiler makers' boiler, the repairs are more efficiently executed by the builders themselves as their conveniences enable them to bend the tubing easier and better than could be accomplished in most boiler shops.

Boilers of the Fig. 31 and 32 type have a large margin of safety, being tested with hydrostatic pressure in some cases

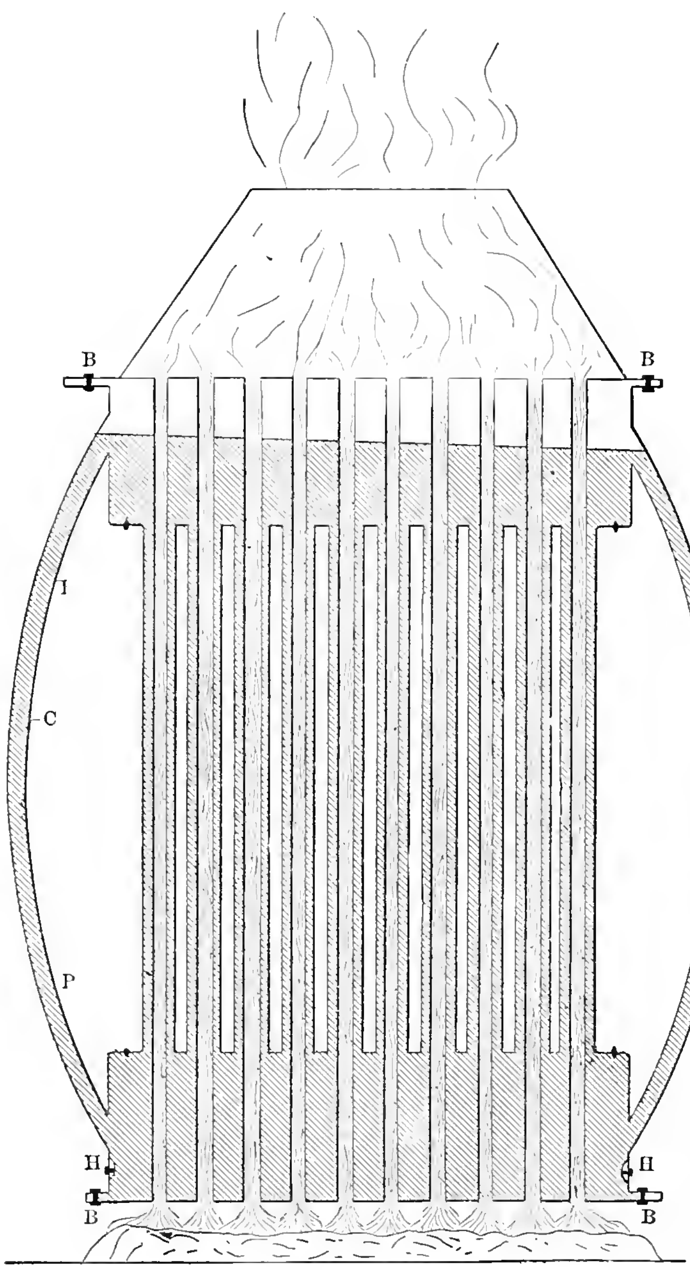


FIG. 33.

as high as 3,000 pounds per square inch. The ordinary working pressure varies between 200 and 450 pounds per square inch.

It was a slight modification of the Fig. 31 type of boiler that furnished power for the Stanley steam racer when it broke the world's record by making a mile in 28 1-5 seconds, the greatest speed attained by any self-propelled vehicle ever built.

A peculiar combination of fire and water-tube boiler is shown in Fig. 33. It consists of an upper and lower annular steam and water chamber, connected by rows of vertical water tubes. These again inclose fire tubes of a still smaller diameter, which extend through the steam and water chambers and discharge into the stack. The top and bottom steam and water chambers are also perforated and contain short fire tubes, not shown in the drawing, which allow some of the gases to circulate around the outside of the water tubes. A downward discharge of the water is provided for by means of the circulating pipes *P-P-P-P*.

There being six tube plates confined within narrow limits, the tubes may be more readily removed by first turning the boiler over on one side. As the fire tubes will be the first to play out, they may be removed as in the case of a locomotive, except that these tubes will have to come out of their own hole. Ordinarily a set of the water tubes will outlast three sets of fire tubes (according to the inventor, Robert Emmet, Fort Worth, Tex.)

If a full set of fire and water tubes is required, the bolts *B-B-B-B*, holding the top and bottom tube plates are first removed. The fire tubes are then cut off and closed in at each end, but not pulled out. Each tube plate is then marked so that it can be replaced in its exact former position. They are then taken down and the fire tubes may be readily withdrawn. The water tubes may then be taken out without fear of the drums sagging any, as the circulating pipes will hold them in position. All the tubes being 1, 2 and 3 inch standard size, the ordinary Boss roller and beading expander are all the finishing tools required.

The 3-inch water tubes are first cut to length, then set and rolled in position without beading or prossing. The tube sheets are then bolted to place, using either a fibrous or metallic gasket. The fire tubes are then applied and allowed to come just flush at the bottom. The bearing portion of the tube sheet being concave at this end, no beading is thought necessary on the tubes, as this method allows the flames to impinge upon the water-protected surfaces only.

Hand holes are provided at *H-H*, so placed as to be directly in line with the opposite plate and also between tube rows. These holes are spaced at regular intervals to facilitate cleaning. The circulating pipes are joined to the shell by riveted connections, and seldom, if ever, need renewal. It may be accomplished, however, by cutting at *C* and replacing with a pipe of the same dimensions, containing a union, either flanged, cast or wrought.

THE LAYOUT AND CONSTRUCTION OF STEEL STACKS

Stacks, or chimneys, serve two objects, the first and most important being that they create a draft or current of air (equal in intensity to the difference between the weight of the column of hot gases inside the chimney and a column of air outside of the same height and sectional area) through the furnace, so that a sufficient quantity of air is brought into contact with the fuel in a certain space of time to produce the desired rate of combustion.

The factors which determine the capacity of a stack to produce a certain draft are the height of the stack, the difference in temperature between the air outside and the gases inside, and the friction opposing the flow of the gases through the furnaces, boilers, up-takes and the stack itself, while the capacity of the stack to handle various quantities of hot gases depends upon the velocity and density of the gases and the sectional area of the stack. Since the density of the gases decreases with an increase in temperature, it is evident that to produce a strong draft the temperature of the gases should be as high as practicable without undue loss of heat. Since, however, 550 degrees F. is the temperature at which the maximum weight of gas will be delivered, the temperature will not have any very appreciable effect in determining the size of the stack.

The main points to be considered, therefore, are the height and area. The height must be great enough to produce sufficient draft to burn the kind of fuel to be used at a certain desired rate of combustion, and the sectional area must be large enough to carry off the gases produced at this rate of combustion.

In laying out a stack for boilers of a certain horsepower, if either the height or the area is assumed, the other quantity may be determined from the following formula:

$$H.\ P. = 3.33\ (A - 0.6\ \sqrt{A})\ \sqrt{H},$$

where $H.\ P.$ = horsepower of the boilers, A = area of stack in square feet, H = height of stack in feet. This equation, which was deduced by Mr. William Kent some time ago, has been widely used, and when the assumptions upon which it is based and its limitations are fully understood it can be depended upon to give very good practical results. The assumptions upon which the formula are based are: That the draft varies as the square root of the height of the stack, and that the effective area shall be computed from a diameter 4 inches less than the actual diameter of the stack. The constants for this equation were determined from the performance of a typical chimney, and are, therefore, entirely empirical.

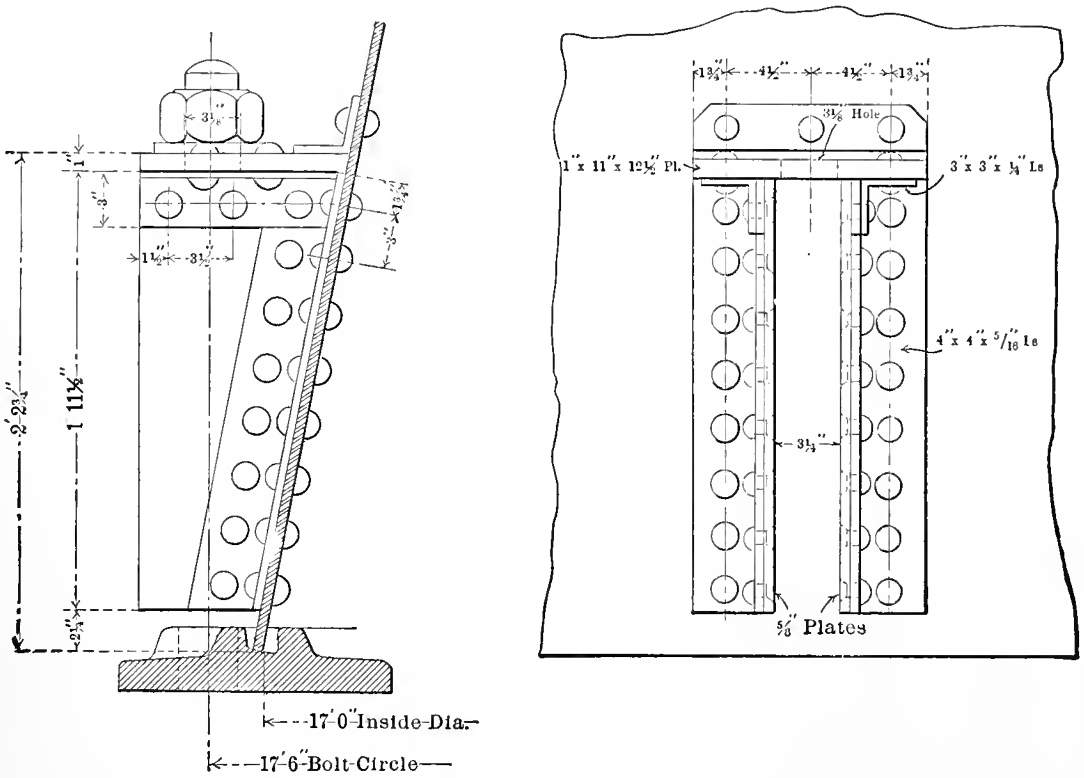


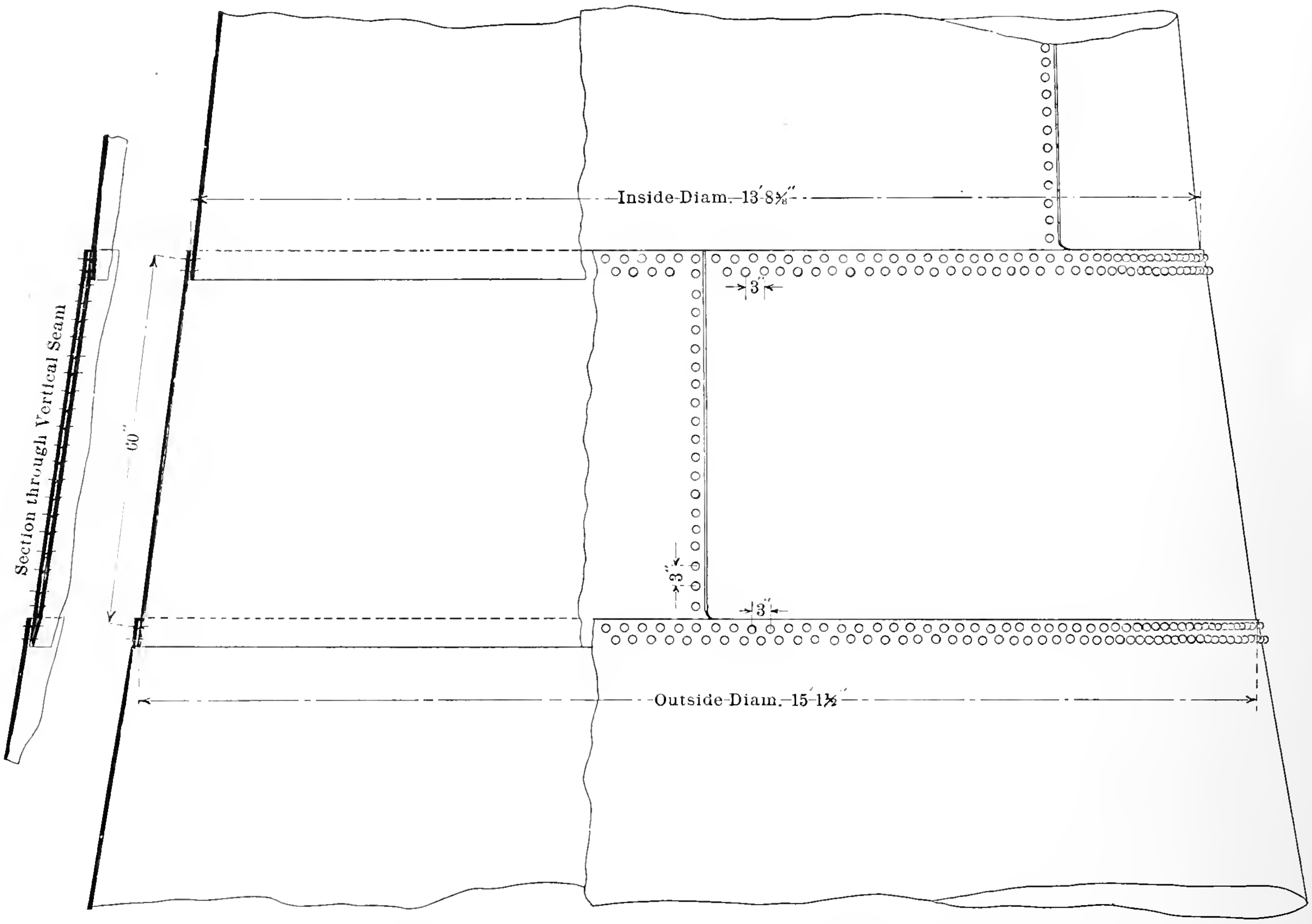
FIG. I.—METHOD OF ANCHORING SELF-SUPPORTING STEEL STACKS.

Assuming a coal consumption of 5 pounds per horsepower per hour, Table No. 1 was compiled by Mr. Kent, the values being computed by means of the above equation. In any case, if the horsepower is given and the height assumed, as is frequently the case in the design of a stack, the effective area E, which is a section whose diameter is 4 inches less than the diameter of the stack, may be determined from the following formula:

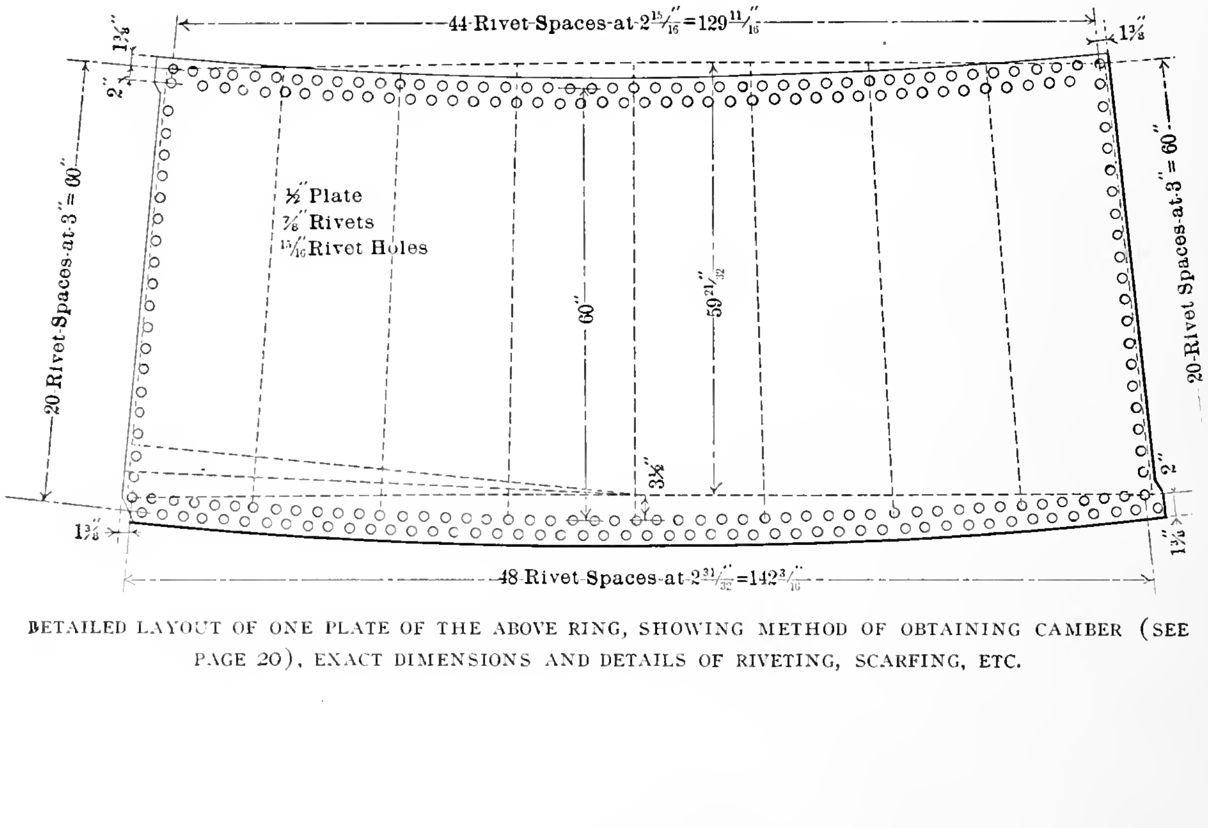
$$E = \frac{.3\ H.\ P.}{\sqrt{H}}$$

The area of the stack is frequently made equal to about one-eighth the grate area and then the height is determined to give the required draft.

Steel stacks are of two kinds, guyed and self-supporting.



DETAILS OF SECOND COURSE OF PLATING OF STACK 191 FEET HIGH BY 10 FEET DIAMETER, THE RING TO BE CONSTRUCTED OF FOUR PLATES ½ INCH IN THICKNESS WITH DOUBLE-RIVETED CIRCUMFERENTIAL SEAMS AND SINGLE-RIVETED VERTICAL SEAMS.



DETAILED LAYOUT OF ONE PLATE OF THE ABOVE RING, SHOWING METHOD OF OBTAINING CAMBER (SEE PAGE 20), EXACT DIMENSIONS AND DETAILS OF RIVETING, SCARFING, ETC.

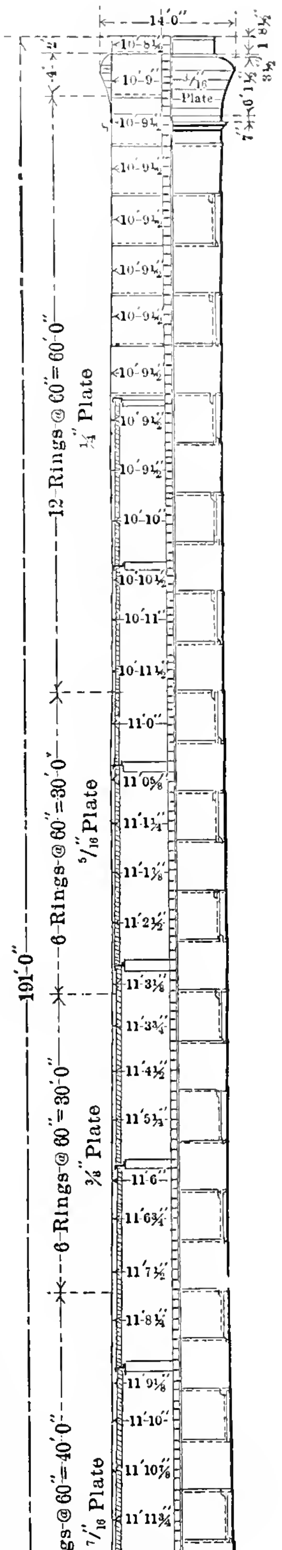


FIG. 2.—SELF-SUPPORTING STEEL STACK, 191 FEET HIGH BY 10 FEET DIAMETER.

Guyed stacks depend for their stability upon ropes or wires which are attached to the stack by means of an angle-bar or Z-bar ring, at about two-thirds the height of the stack from the ground. There should be at least four guys for a stack, the rods being usually of ½ or ¾-inch iron, depending upon the size of the stack, since the load which they are to support is that due to the pressure of the wind upon the surface of the stack. This is usually figured as 25 or 30 pounds per square inch of projected area. If the stack is very tall, two sets of guys should be used, fastened at different points on the stack. Since a guyed stack must be only strong enough to sustain its

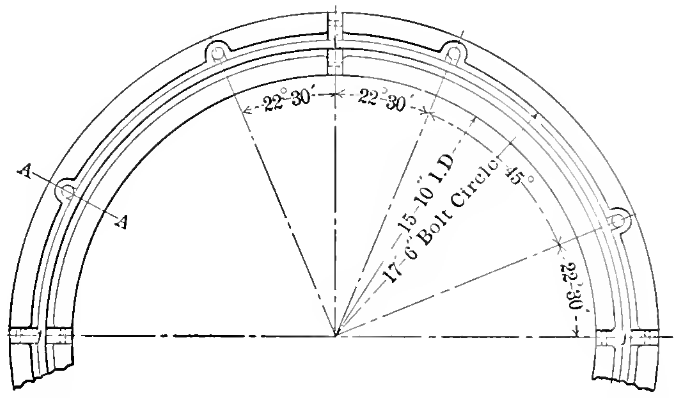


FIG. 3.—SECTION OF BASE PLATE USED WITH SELF-SUPPORTING STACK.

own weight, it is a light and cheap form of stack to construct, and is usually made in the form of a straight tube of in-and-out rings. In that case all the sections can be rolled to a cylindrical shape and riveted up in the shop, and afterwards easily erected in position without the aid of expensive scaffolding. As guyed stacks are seldom much over 100 feet high, the thickness of plate used is usually No. 10, 12 or 14-gage. Due to

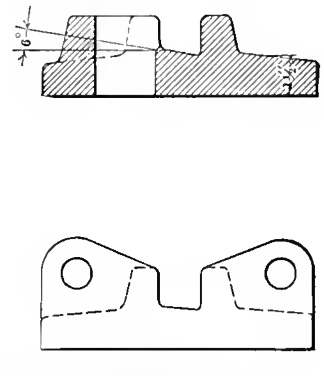


FIG. 4.—SECTIONAL VIEW AND FLANGE OF BASE PLATE.

their lightness, this form of stack does not require a substantial foundation, and they are frequently set directly upon the breeching of the boiler.

Self-supporting stacks, an illustration of which is given in Fig. 2, require a more careful design, as they must sustain not only the load due to their weight but also that due to the pressure of the wind. They are usually given a taper of about 1/16 inch to the foot, and the bottom is flared out or made bell-shape, to give added stability, the diameter of the base being about one-tenth the height of the stack. The stack rests upon a base plate usually of cast iron of the shape shown in Fig. 3. This base is usually cast in four or more sections, which are fastened together with bolts through the flanges or lugs, which are cast on the ends of each section, as shown in Fig. 4. The

base plate for small self-supporting stacks is sometimes cast in one piece with cored rivet holes in the flange. The lower course of the plating of the stack is then riveted directly to the base plate, which in turn is anchored to the foundation by holding-down bolts. This construction is, however, not reliable, and should not be used for large stacks, since the wind pressure brings a tension stress on one side of the stack at the base where it is fastened to the cast-iron ring, and the cast iron, which has a low tensile strength at best, cannot be relied upon to sustain the load, as there are frequently blow holes or other imperfections in the casting.

The construction which is now used to replace this is shown in Fig. 1. The lower course of the stack simply rests in the groove of the base plate without being riveted to it. The holding-down or anchor bolts are fastened directly to the shell through steel brackets, as shown. Two bracket plates, of the form shown in the detail, Fig. 1, are fastened by angles to the shell a few inches apart. Riveted to the top of these brackets is a heavy plate in which a hole just large enough to receive the anchor bolt has been drilled. The tension stress is then transmitted from the shell to the bolt through steel, whose strength can be accurately figured, and which can be depended upon to sustain the load for which it is designed.

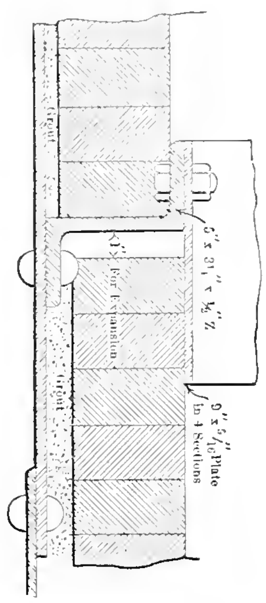


FIG. 5.—DETAILS OF MANNER OF SUPPORTING LINING.

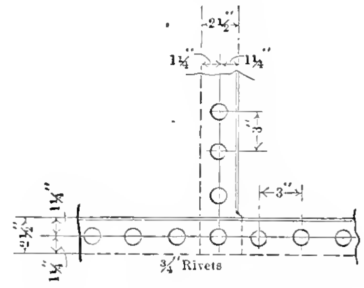


FIG. 6.—DETAIL OF RIVETING OF TOP RINGS.

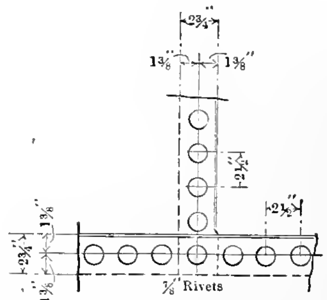


FIG. 7.—DETAIL OF RIVETING ABOVE 65 FEET.

The foundation for the stack depends upon the character of

TABLE NO. I.

Diameter in Inches.	Area A in Sq. Ft.	Effective Area $E=A-.6\sqrt{A}$ Sq. Ft.	Height of Stack in Feet.													
			50	60	70	80	90	100	110	125	150	175	200	225	250	300
			Commercial Horsepower.													
18	1.77	.97	23	25	27	29										
21	2.41	1.47	35	38	41	44										
24	3.14	2.08	49	54	58	62	66									
27	3.98	2.78	65	72	78	83	88									
30	4.91	3.58	84	92	100	107	113	119								
33	5.94	4.48	....	115	125	133	141	149	156							
36	7.07	5.47	....	141	152	163	173	182	191	204						
39	8.30	6.57	....	....	183	196	208	219	229	245	268					
42	9.62	7.76	....	....	216	231	245	258	271	289	316	342				
48	12.57	10.44	....	....	....	311	330	348	365	389	426	460	492			
54	15.90	13.51	....	....	....	....	427	449	472	503	551	595	636	675		
60	19.64	16.98	....	....	....	....	536	565	593	632	692	748	800	848	894	
66	23.76	20.83	....	....	....	....	....	694	728	776	849	918	981	1,040	1,097	1,201
72	28.27	25.08	....	....	....	....	....	835	876	934	1,023	1,105	1,181	1,253	1,320	1,447
78	33.18	29.73	....	....	....	....	....	....	1,038	1,107	1,212	1,310	1,400	1,485	1,565	1,715
84	38.48	34.76	....	....	....	....	....	....	1,214	1,294	1,418	1,531	1,637	1,736	1,830	2,005
90	44.18	40.19	....	....	....	....	....	....	.....	1,496	1,639	1,770	1,893	2,008	2,116	2,318
96	50.27	46.01	....	....	....	....	....	....	.....	1,712	1,876	2,027	2,167	2,298	2,423	2,654
102	56.75	52.23	....	....	....	....	....	....	.....	1,944	2,130	2,300	2,459	2,609	2,750	3,012
108	63.62	58.83	....	....	....	....	....	....	.....	2,090	2,399	2,592	2,771	2,939	3,098	3,393
114	70.88	65.83	....	....	....	....	....	....	.....	.....	2,685	2,900	3,100	3,288	3,466	3,797
120	78.54	73.22	....	....	....	....	....	....	.....	.....	2,986	3,226	3,448	3,657	3,855	4,223
132	95 63	89.18	....	....	....	....	....	....	.....	.....	3,637	3,929	4,200	4,455	4,696	5,144
144	113.10	106.72	....	....	....	....	....	....	.....	.....	4,352	4,701	5,026	5,331	5,618	6,155
156	132.73	125.82	....	....	....	....	....	....	.....	.....	5,133	5,540	5,924	6,285	6,624	7,240
192	201.06	192.55	....	....	....	....	....	....	.....	.....	7,855	8,483	9,066	9,618	10,137	11,090

the soil upon which it is to rest, and should be designed by some one who has had considerable experience in such work. The opening from the flues leading from the boilers to the stack should be located, if possible, underneath the stack, as any opening cut in the shell greatly reduces the strength of the stack.

Nearly all self-supporting stacks and some guyed stacks are protected by firebrick lining. This lining is made sufficiently heavy to sustain its own weight, and is not connected to the

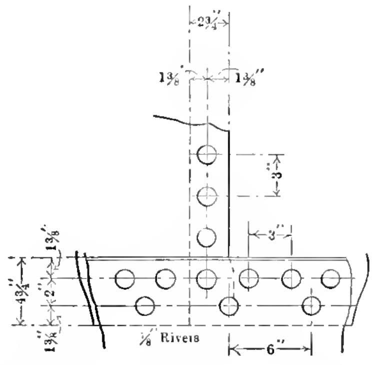


FIG. 8.—DETAIL OF RIVETING ABOVE 25 FEET.

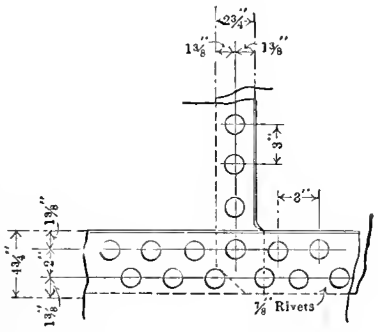


FIG. 9.—DETAIL OF RIVETING AT BASE.

shell except at intervals of 40 or 50 feet. A lining is seldom continued clear to the top of the stack, as the gases are sufficiently cool by the time they have traveled about three-quarters the length of the stack, so that no injury will result from their contact with the steel. The sections of lining are supported as shown in Fig. 5. A Z-bar ring is riveted inside the stack, and to the inner flange of the bar a wide plate is bolted, which extends several inches below the bar. The lower section of the lining extends to within about $1\frac{1}{2}$ inches of the Z-bar, in order to allow for expansion and is supported by the plate. The next section of lining rests upon the Z-bar, and is supported through it by the shell. An inch or so of space is left between the lining and the shell to allow for expansion.

The top of a stack is usually flared out for the sake of appearance to form a cornice or cap. This cap is made of light plates and, of course, has nothing to do with the strength or stability of the stack. In order to stiffen the top of the stack an angle or Z-bar ring is usually placed around it, while just below the cap another Z-bar ring is riveted to the shell to provide a place for attaching scaffolding for painting the stack. For this purpose also a light iron ladder is usually riveted to one side of the stack. Sometimes in the case of a very large stack a light spiral staircase runs part way up the outside of the stack.

The stability of the stack may be determined as follows: Find the total weight of the stack and lining. This may be considered as a vertical force acting downward through the middle of the foundation. Find the total pressure on the chimney, which would be approximately 25 $\times$ the height $\times$ the diameter. This may be considered to act in a horizontal direction at the middle point of the chimney, so that its moment about the base would be the total force $\times$ ½ the height of the chimney. Divide this moment, due to the wind pressure, by the weight of the chimney, and the result will be the distance from the middle of the foundation to the resultant force due to the combined forces of wind pressure and weight. For stability

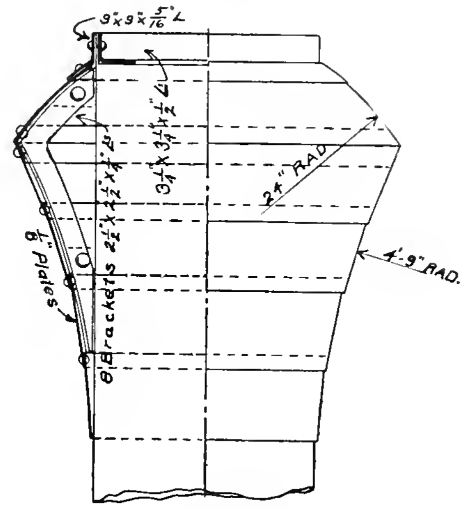


FIG. 10.—CAP MADE WITH CONICAL RINGS.

this force should act within the middle third of the width of the base.

The stress per lineal inch at any section may be determined from the following formula:

The stress per lineal inch at any section = moment due to wind pressure in inch pounds $\div$ ¼ $\times$ 3.1416 $\times$ (diameter in inches)^2. Assuming a safe fiber stress of 10,000 pounds per square inch, the thickness of plate necessary to sustain this stress may be figured from the following formula:

Thickness in inches

$$= \frac{10{,}000 \times \text{the efficiency of the horizontal joint.}}{\text{stress per lineal inch}}$$

The calculation for the stress per lineal inch should be made at a number of sections in order to be sure that the stress at any point does not exceed the safe working stress of the material. If desired, more elaborate computations may be made for the strength of the riveted joints subjected to the bending strain due to the wind pressure. In the case of the horizontal joint the rivets on both the windward and leeward side of the stack will be in shear, although the joint on the windward side will be in tension and on the leeward side in compression.

In order to follow through the calculations which must be made in the layout of a particular stack, assume that it is required to build a stack for boilers which have a total horsepower of 285 and a total grate area of about 60 square feet. The effective area of the stack should be about one-eighth the total grate area, or about $7\frac{1}{2}$ square feet. The diameter corresponding to this area would be about 9 feet 8 inches. The actual diameter of the stack, however, according to the as-

sumptions which were made, should be 4 inches greater than this, or about 10 feet. Using the equation

$$\text{Horsepower} = 3.33\ (A - .6 \times \sqrt{A})\ \sqrt{H},$$

and substituting 285 as the value of the horsepower and 10 × .7854 as the value for A, the height of the stack may be determined:

$$285 = 3.33\ (7.854 - .6\ \sqrt{7.854})\ \sqrt{H}$$

$$\sqrt{H} = 13.8$$

$$H = 191$$

Therefore, the required dimensions of the stack are: Height, 191 feet; diameter, 10 feet. The details of a stack built to these dimensions are shown in Fig. 2. The actual diameter of the shell of the stack will be greater than 10 feet, since the

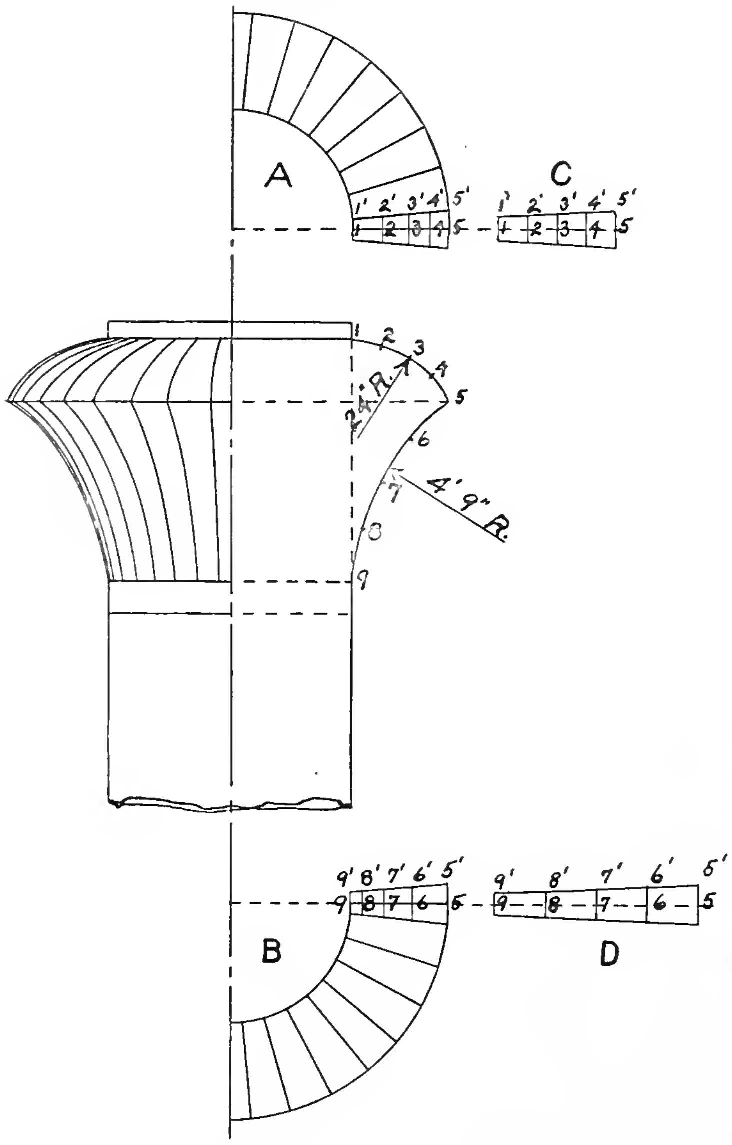


FIG. 11.—LAYOUT OF CAP WITH VERTICAL STRIPS.

inside diameter of the lining should be at least 10 feet. As the lining at the top should be approximately 4 inches thick, the actual diameter of the stack at the point where the lining is stopped should be about 10 feet 9½ inches.

A computation should be made for the thickness of plate at intervals of 25 or 30 feet throughout the height of the stack. Using the formula quoted in the first part of the article for the thickness of plate, we have at a height of 25 feet:

$$T = \frac{11 \times 166 \times 30 \times \dfrac{166}{2} \times 12}{.7854 \times (12.25 \times 12)^2 \times 10{,}000 \times .75}$$

$T = .43$, or, approximately, 7/16 inch. This is assuming a mean diameter of 11 feet with a diameter of 12 feet 3 inches at the height of 25 feet, and that the horizontal seam is double riveted with an efficiency of 75 percent.

Making the same computation at a height of 65 feet, where the diameter is 11 feet 7 inches, and the horizontal seam single riveted with an efficiency of about 60 percent, T is found to be about .344, or ⅜ inch. At a height of 95 feet, where the diameter is 11 feet 3 inches, T is found to be about .21 inch. As it would not be advisable, however, to use anything less than ¼-inch plate, the next 30 feet of the stack should be con-

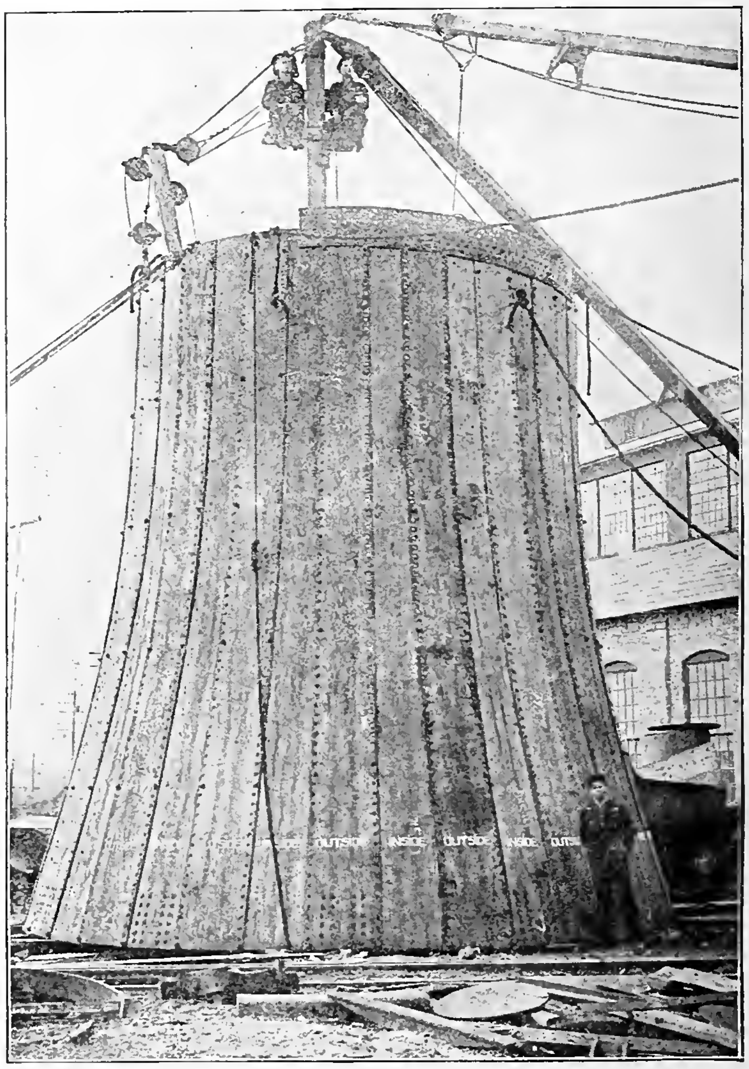


FIG. 12.—BELL SHAPED PORTION OF SELF-SUPPORTING STACK.

structed of 5/16-inch plate, leaving only the last 60 feet of ¼-inch plate.

The details of the riveting for the different thicknesses of plate are shown in Figs. 6, 7, 8 and 9. It will be seen that the double-riveted horizontal seams give an efficiency of about 70 percent, while the single-riveted seams give an efficiency of at least 60 percent.

The stack is constructed of rings each 60 inches wide, made up of three plates. Where the diameter exceeds 12 feet each ring should be made in four sections. Each ring is in the form of the frustum of a right circular cone, and may be laid out according to any of the methods described in the first chapter under "conical surfaces where the taper is small." In the stack shown in Fig. 2 each ring is an inside ring at its lower edge and an outside ring at its upper edge. This style of construction is frequently reversed. In de-

termining the length of the plates which form a ring an allowance of about seven times the thickness of the plate should be made between an outside and an inside ring.

The plates are sheared, punched, scarfed and rolled in the shop, but the plates which form a ring are not riveted together until they are erected in place. The scaffolding is built up on the inside of the stack, the plates being hoisted by means of a short jib crane on top of the scaffold. The seams should all be calked after riveting, so that there will be no leakage of air into the stack. This is one of the important advantages which a steel stack has over a brick chimney, since the brick work in a chimney frequently becomes loose and allows air to leak into the chimney, impairing the draft.

A cap or cornice for a stack may be constructed in one of two ways: either as shown in Fig. 10 of narrow plates in the form of circular rings, or, as shown in Fig. 11, of narrow strips of plate which run lengthwise of the stack. In the first case, the layout of each ring is obtained in the ordinary way for finding the development of the frustum of a right circular cone. The dimensions for the diameter at the top and bottom of the ring and for the width of the ring being taken from a full-sized sectional drawing similar to that shown in Fig. 10.

The plate used for these rings is seldom more than 1/8 or 3/16 inch thick, and, therefore, if made in narrow rings, the cap will have a smooth appearance. The proportions governing the general outline of the cap will depend upon the height and diameter of the stack.

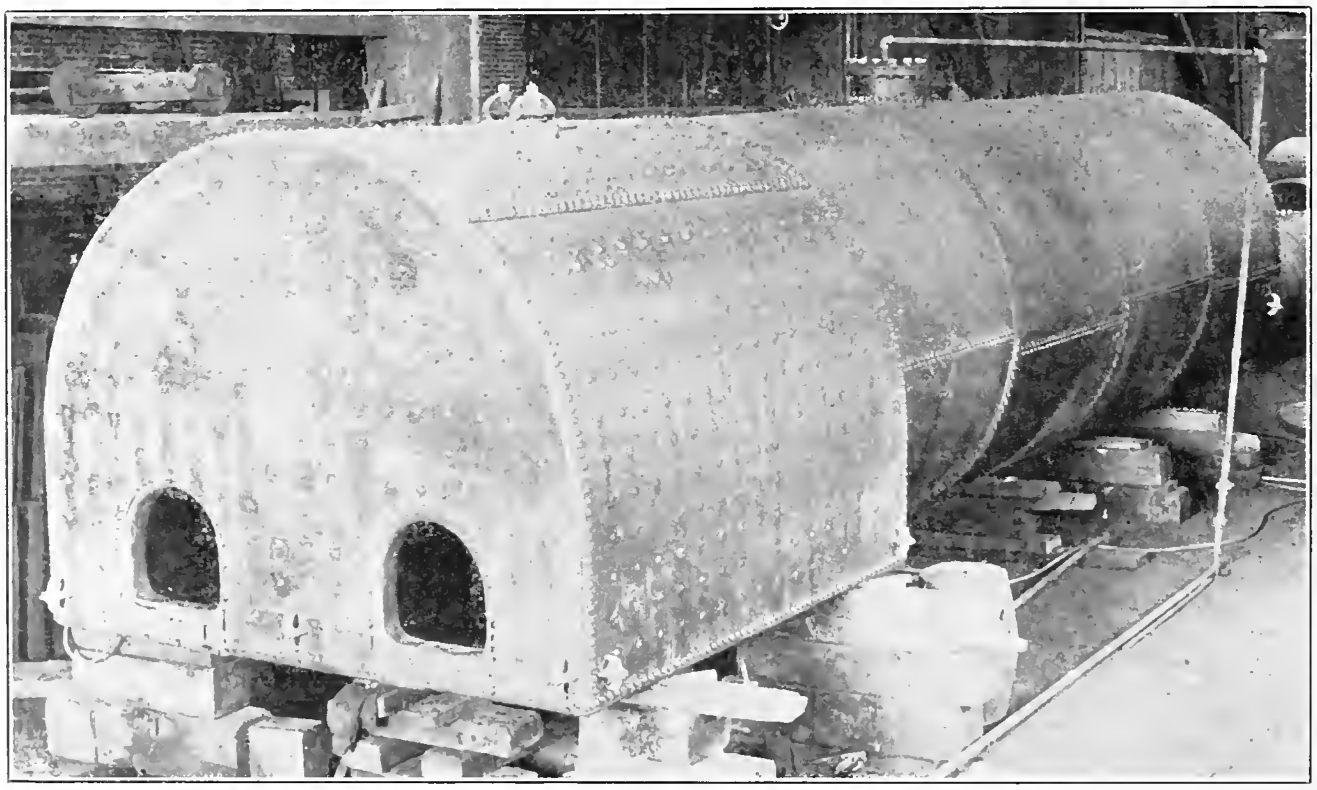
The plates which form the cap are supported by brackets, as shown in the detail, Fig. 10. In this case eight brackets are provided, made of 2½ by 2½ by ¼-inch angle-bars, forged to conform to the outline of the cap. These brackets are riveted by clips to the shell of the stack. A 3 by 3 by 5/16-inch angle is riveted around the upper edge of the cap after it has been beveled to the proper angle. A similar angle is riveted at the corner of the cap. The plates are riveted together and are secured to the angle-iron brackets by 5/16-inch rivets spaced at about 4 inches pitch.

The layout of the strips for a cap constructed according to the second method is shown in detail in diagrams *A, B, C* and *D*, Fig. 11. The outline of the cap is first drawn full size, and the arc 1-5 is divided into any number of equal spaces, as at points 2, 3 and 4. These points are projected to the plan view at *A*. In order to give a smooth appearance to the cap, it should be constructed of from twenty to thirty strips. In this case thirty-two have been taken, thus dividing a quarter of the cap into eight equal strips. Having divided the quarter plan *A* into eight equal spaces, the pattern for one of these strips may be laid out as at *C*, where 1-5 is made equal to the length of the arc 1-5 in the outline of the cap, and the offsets 1-1′, 2-2′, 3-3′, etc., are measured from the corresponding lines in *A*.

In a like manner the pattern for the lower part of the cap may be obtained as at *D*, where the length of the strip 9-5 is made equal to the length of the arc 9-5 in the outline, and the offsets 9-9′, 8-8′, 7-7′, etc., are taken from the corresponding lines in the plan view *B*. The laps and allowances which must be made, due to bending the material, should be added to these patterns. The brackets and frame work for this cap are similar to those shown in Fig. 10.

Instead of making the lower rings of a very large and heavy stack in the form of conical surfaces, a section from 15 to 20 feet high is frequently made bell shape, as shown in Fig. 12. This gives the stack a more graceful appearance, and it can be so constructed as to give a firm foundation for the rest of the stack. The bell portion, like the fancy top or cap shown in Fig. 11, is constructed of narrow strips of plate which run lengthwise of the stack. These, as may be seen from the illustration, are joined with lap seams, the alternate strips being outside and inside. The layout of these strips may be obtained in the same way as the strips for the cap, which was described in connection with Fig. 11.

SPECIAL ELBOW USED AS AN EXHAUST CONNECTION FROM A TURBINE CASING TO A CONDENSER, CONSTRUCTED OF 7/16-INCH PLATE AND RIVETED TO CAST-IRON FITTINGS AT EACH END.



A LOBSTER BACK RETURN FLUE MARINE BOILER, 8 FEET 9 INCHES DIAMETER BY 33 FEET LONG, CONSTRUCTED WITH TWO FURNACES AND THREE COMBUSTION CHAMBERS; TWO FLUES, 24 INCHES DIAMETER; TWO FLUES, 13 INCHES DIAMETER, AND 68 TUBES, 3 INCHES DIAMETER BY 16 FEET LONG; STEAM PRESSURE, 55 POUNDS PER SQUARE INCH

MISCELLANEOUS PROBLEMS IN LAYING OUT

A Y-Breeching.

Figs. 1 and 2 represent a style of breeching that has been in use for over thirty years. I believe it was first designed by the Erie City Iron Works, of Erie, Pa. It is very simple in construction and easy to make, and in my judgment, when properly proportioned, makes a very neat job. In some shops where a great variety of sheet iron work is done, there is generally a large number of pieces lying around the shop large enough to make one of these breechings or the greater part of it. By making it in small sections as shown, it is easily worked up and put together.

To lay out such a breeching, first strike up one-half of the side elevation, Fig. 3, the desired size as follows: First lay down the center line *JR*. Then lay out the band or upper

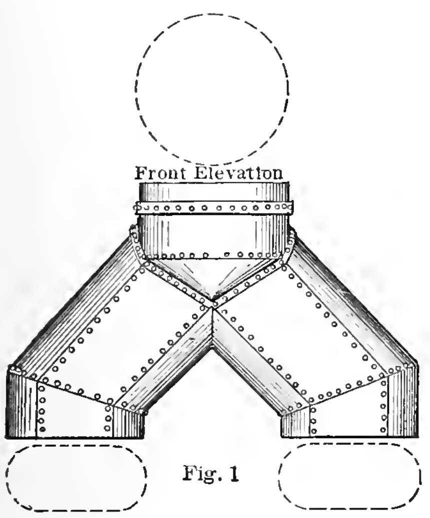


Fig. 1

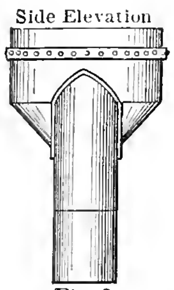
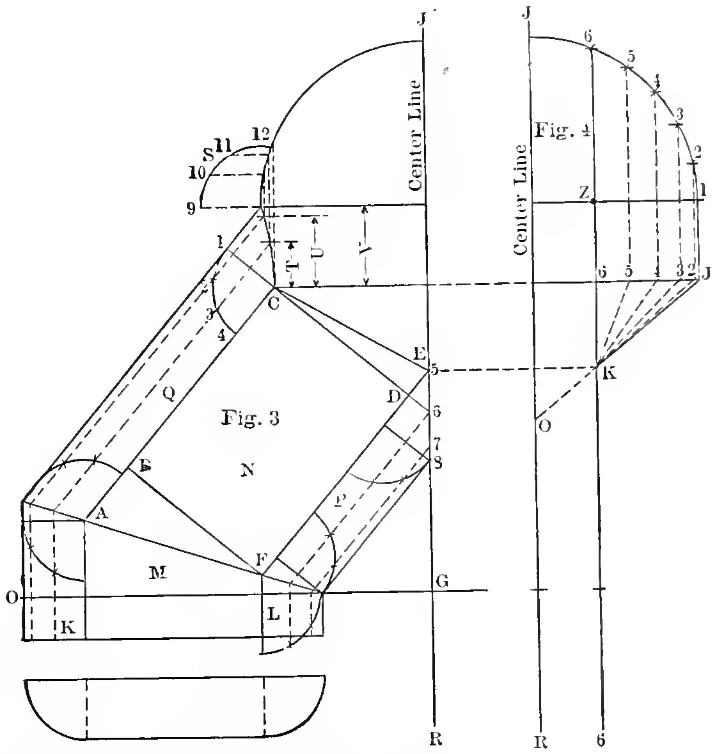


Fig. 2

part. Then the branch piece; also sketch up the slope of the connection at the bottom, as shown, and erect vertical lines from where the circular part begins. This represents the round part of the leg. Now, strike square lines across all of the different pieces in Fig. 3, and on the round part strike the quarter circles and divide them into any number of equal parts as shown, in this case three parts, and number them 1, 2, 3 and 4. Then extend lines through these points at both ends as shown. Now strike the quarter circle on top, which represents the diameter of the part where the stack is to fit, and on the side strike another quarter circle, as shown at *S* in Fig. 3, equal in diameter to the round part of the leg, and divide it into the same number of parts as at 9, 10, 11 and 12. Extend these lines to cut the large circle as shown. Now drop the dotted lines as shown to cut the lines on the leg, and a line traced through these points will be the miter line, or, in other words, will be the points where the leg will strike the main diameter. We are now ready to lay out the plates which make up the leg. You will note that each part, as lettered *K, L, M, N, P* and *Q* in Fig. 3, has a similar letter on the plates which are laid out.

TO LAY OUT THE LEG PLATES.

Take *K*, Fig. 3, and lay it out as shown in plate *K*. First find the circumference and space it off in twice as many parts as the quarter circle in Fig. 3 is divided into, and as shown in plates *K* and *Q*, and number them as 4, 3, 2, 1, 2, 3 and 4. Then take the distance from the line *OG*, Fig. 3, to where line 1 strikes the miter line, and mark off a corresponding distance from line *OG*, plate *K*, on the center line. Now take the length of line 2 from *OG*, Fig. 3, and mark off a corresponding distance on line 2 each side of the center line on plate *K*. Then get the length of lines 3 and 4 from Fig. 3 and transfer them to plate *K*. Then by tracing lines through these points you will have the miter line on plate *K*, and by laying out rivet



holes on the miter line, also on the seam, and add for laps, plate *K* will be complete.

To lay out plate *Q*, locate lines 4, 3, 2, 1, 2, 3 and 4 and make them any length longer than the plate. Now the shop way of laying this out is to take a strip of iron, lay down on Fig. 3, and mark the square line on either end, and then mark the distance from the square line to the miter line on both ends as found by the quarter circles on lines 1, 2, 3 and 4, and transfer these lengths to plate *Q* on lines 4, 3, 2, 1, 2, 3 and 4, and lines drawn through these points will be the miter line or line of rivet holes. Now, by laying out the necessary rivet holes around the edges and adding for lap, plate *Q* will be complete. Plates *P* and *L* are laid out in the same manner.

TO LAY OUT THE FLAT PART OF SIDES.

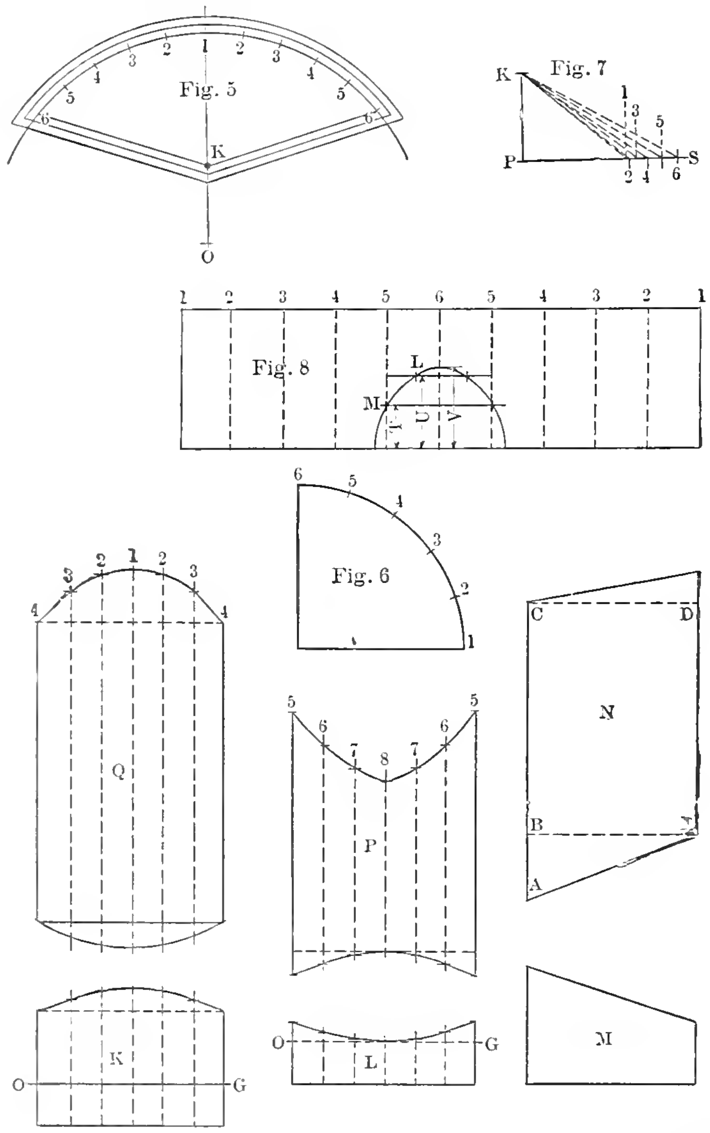
All that is necessary to develop the side pieces is to first start on plate *M* and lay down the bottom line, then erect the perpendicular lines, taking the miter line as the height, and draw the miter line as shown in plate *M*. Then locate your rivet holes on the seams and the miter line and add for lap and plate *M* will be complete.

Plate *N* is laid out in a similar manner, or, in other words, transfer the lines on Fig. 3, plate *N*, to the sheet which you

wish to use for this purpose, locate your rivet holes, add for lap, and the development of the sheets for the leg will be complete.

TO LAY OUT TOP, OR FIG. 8.

For this purpose Fig. 6 may be used. Fig 6 is a quarter circle of the top ring divided into five spaces. Fig. 8 represents one-half of the top spaced from Fig. 6 from 1, 2, 3, 4, 5, 6, 5, 4, 3, 2 and 1. The object of Fig. 8 is to show how to lay out the hole where the round part of the leg, Fig. 3, strikes the top. First take the distances marked *T*, *U* and *V*, Fig. 3,



and transfer them to Fig. 8 as shown. Now, take the lengths of lines 9, 10, 11 and 12 on Fig. 3 from the quarter circle *S* and transfer them to Fig. 8, each side of the center line 6, as shown at *L*, *M* and the bottom line; then a line traced through these points will be the cut out of the hole.

TO LAY OUT THE BREAST PLATE.

First sketch up Fig. 4. Line *JR* is the center line. Then strike the quarter circle and divide that portion where the breast plate strikes into any number of equal parts, in this case five, and number them as 1, 2, 3, 4, 5 and 6, and square these lines down to the base of the main ring as denoted by 6, 5, 4, 3, 2 and *J*. Now extend these dotted lines to point *K* and you are ready to lay out the breast plate, Fig. 5. One way to develop this plate is on the same principle as a cone is laid out. Another is by triangulation. To lay this out by the first method is to extend line *JK*, Fig. 4, to the center line *O*, and with radius *OJ* strike the curved line on Fig. 5, using *O* as a center, and with dividers set around the circle, Fig. 4, mark off points 1, 2, 3, 4, 5 and 6, Fig. 5. Now get the length of line *JK*, Fig. 4, and from point 1 of Fig. 5 mark point *K*. Now draw lines from points 6-6 to *K*, and you have the flange line. Now add for the necessary flanges and lay out your rivet holes and the sheet will be complete.

TO LAY OUT THE BREAST PLATE BY TRIANGULATION.

Strike up Fig. 7 in the following manner: First lay down line *PS* and strike the perpendicular line *PK* at right angles. Next take the perpendicular height, Fig. 4, from 6 to *K*, and mark off from *P* to *K*, Fig. 7. Now with *Z*, Fig. 4, as a center, take the distances from *Z* to 1, *Z* to 2, *Z* to 3, *Z* to 4, *Z* to 5 and *Z* to 6, and mark off a corresponding distance on line *PS*, Fig. 7, as shown, numbered 1, 2, 3, 4, 5 and 6; then extend lines from these points to point *K*, as shown by dotted lines. Then you are ready to develop Fig. 5 by triangulation.

Take the distance from *K* to 1, Fig. 7, and mark off a corresponding distance from *K* to 1, Fig. 5. Now with your dividers set to spaces on the circle, Fig. 4; mark one space, Fig. 5, each side of 1 as 2, 2. Then with tram points set from *K* to 2, Fig. 7, mark off a corresponding distance from *K* to 2, Fig. 5. Then from points 2 mark off another space at 3 each side, and with tram points set from *K* to 3, Fig. 7, mark off the same distance from *K* to 3, Fig. 5; then take the length of the rest of the lines in Fig. 7 from *K* to 4, *K* to 5 and *K* to 6, and transfer to Fig. 5, each time marking one space with the dividers as shown, and you will get the same results as you did by the first method. Then add for your rivet holes and flanges and the sheet will be complete.

Layout of a Tank, 85 Feet in Diameter by 30 Feet in Height.

Large steel tanks are seldom required to carry any pressure except that due to the head of the fluid which they contain. Therefore, the first thing to do in laying out such a tank is to determine the stress on the bottom of the shell, due to the head of water, oil, or whatever fluid the tank is to hold. The stress will be greatest, of course, on the bottom of the shell, and the thickness of shell plates may be decreased from the bottom to the top.

Let us assume that the tank is to be used for softening boiler feed-water; that is, the tank must be strong enough so that it may be entirely filled with water. The maximum pressure on the tank will, then, be that due to a head of 30 feet of water. One cubic foot of water at ordinary temperature, 62 degrees F., weighs 62.352 pounds; that is, a head or depth of 1 foot of water will cause a pressure of 62.352 pounds per square foot, or $62.352 \div 144 = .433$ pounds per square inch. Therefore, a head or depth of 30 feet of water will cause a pressure of $.433 \times 30 = 12.99$ pounds per square inch at the bottom of the tank.

We then have a cylindrical shell 85 feet in diameter with an internal fluid pressure of 12.99 pounds per square inch. The thickness of plate necessary to withstand this pressure may be

found by the ordinary formula for finding the thickness of a boiler shell.

If t = thickness of plate.
p = pressure in pounds per square inch.
D = inside diameter of tank in inches.
F = factor of safety.
Ts = tensile strength of the steel in pounds per square inch.

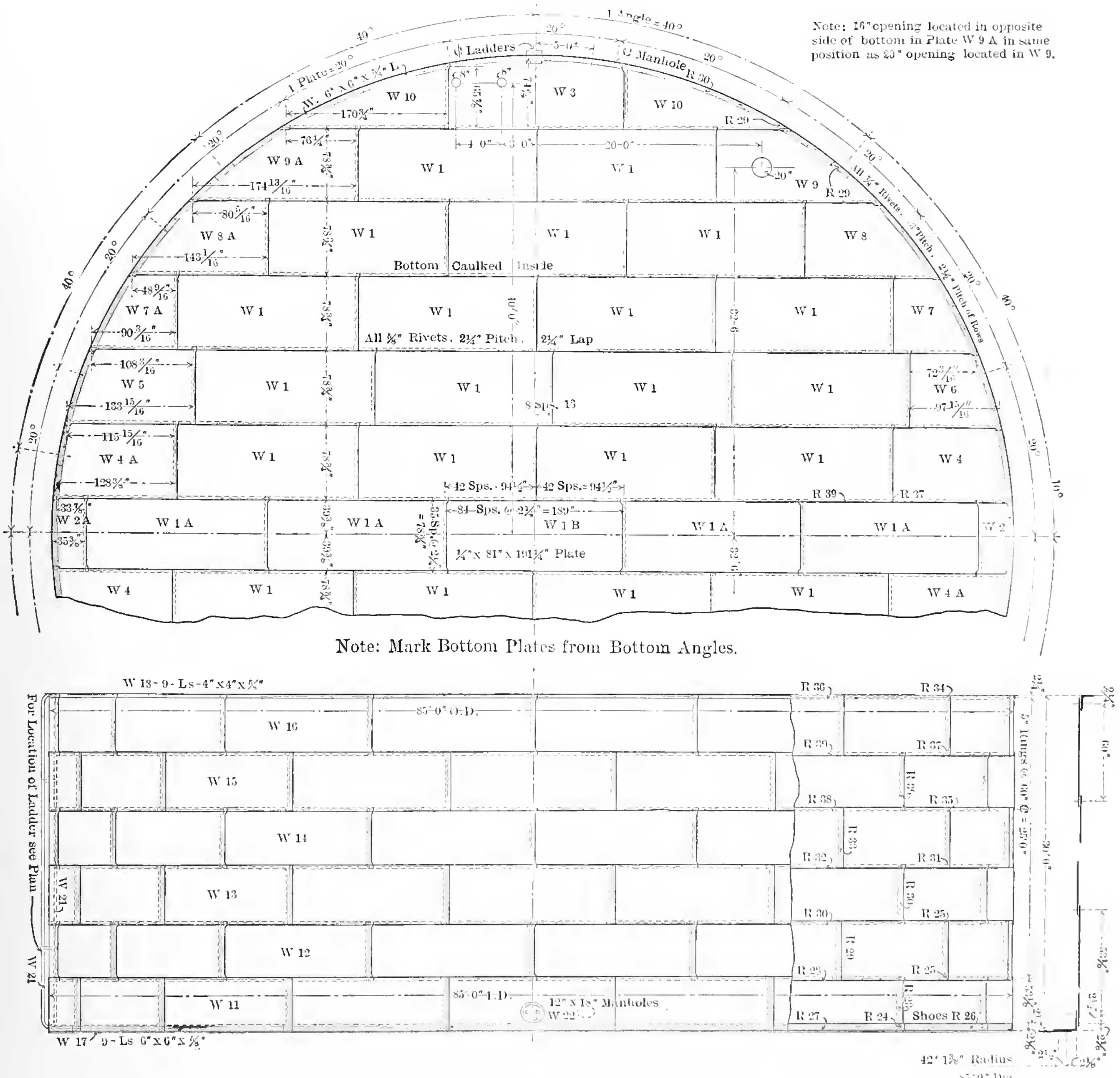


FIG. I.—PLAN AND ELEVATION OF STEEL TANK 85′ BY 30′.

E = efficiency of riveted joint.

Then
$$t = \frac{p \times D \times t}{Ts \times E \times 2}$$

p in this case we have found to be 12.99. D is 85×12, or 1,020 inches. F may be taken comparatively small, as the pressure on the tank is small, and the wear on the steel will not be excessive; 4 will be a sufficiently large factor to use. Mild steel of a fair amount of ductility should be used; therefore, its tensile strength should be about 60,000 pounds per square inch. If the vertical seams are made with a treble riveted lap joint, an efficiency of 75 percent may be easily obtained. Substituting these values in the formula for the thickness of shell plate, we have

$$t = \frac{12.99 \times 1{,}020 \times 4}{60{,}000 \times .75 \times 2} = .588 \text{ inch.}$$

This is slightly less than ⅝; therefore, use ⅝-inch plate for the bottom course.

As the tank is to be 30 feet high, and plates about 5 feet wide can be easily handled in the shop, make the tank in six rings or courses. Number the rings from bottom to top, 1, 2, 3, 4, 5 and 6. The thickness of plate to be used for the second ring must be computed in the same way in which the thickness of plate for the first ring was found. The pressure on

this ring will be that due to a head of 25 feet of water, or $25 \times .433 = 10.825$ pounds per square inch; therefore,

$$t = \frac{10.825 \times 1{,}020 \times 4}{60{,}000 \times .75 \times 2} = .491 \text{ inch.}$$

Use ½-inch plate for this course.

For the third ring, the pressure is that due to a head of 20 feet of water, or $20 \times .433 = 8.66$ pounds per square inch; therefore,

$$t = \frac{8.66 \times 1{,}020 \times 4}{60{,}000 \times .75 \times 2} = .392 \text{ inch.}$$

Use 7/16-inch plate for this course.

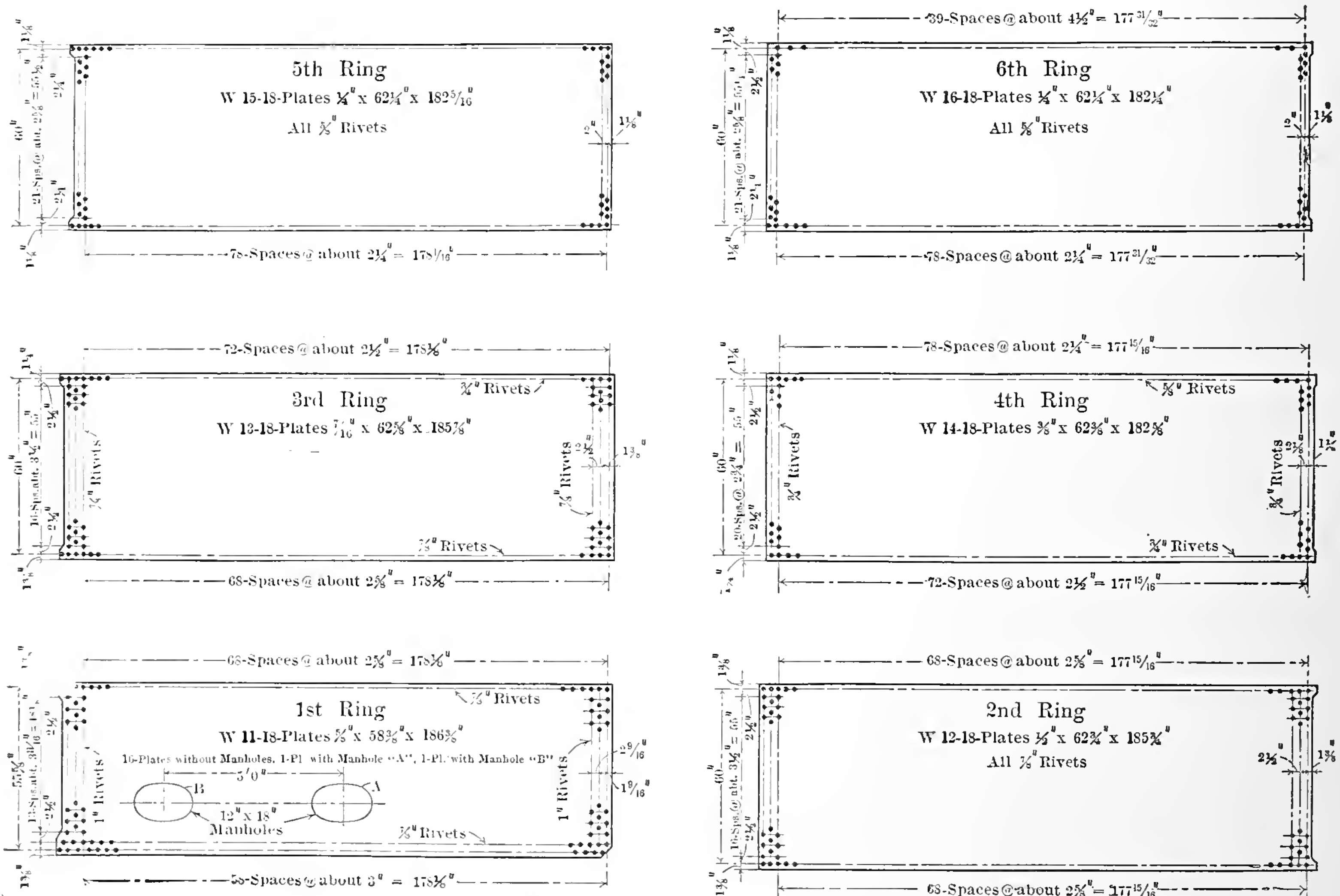
$$t = \frac{4.33 \times 1{,}020 \times 4}{60{,}000 \times .65 \times 2} = .212 \text{ inch.}$$

On such a large tank it would not be advisable, for structural reasons, to use plate less than ¼ inch in thickness; therefore, make both the fifth and sixth rings of ¼-inch plate.

The approximate pressure on the lower ring, due to the weight of the shell, assuming that 1-inch plate weighs 40 pounds per square foot, will be found as follows:

$$\frac{5\,(25 + 20 + 17.5 + 15 + 10 + 10)}{12 \times .625} = \frac{487.5}{12 \times .625} = 651$$

pounds per square inch.



NOTE: All Plates are to be Bevel Sheared for Outside Caulking
Outside of Plates shown

FIG. 2.—DEVELOPMENT OF SHELL PLATES OF STEEL TANK 85′ BY 30′.

For the fourth ring, the pressure is that due to a head of 15 feet of water, or $15 \times .433 = 6.459$ pounds per square inch. As the pressure on this ring is only half of that at the bottom of the tank, the vertical seams may be double instead of treble riveted. The efficiency of the joint will then drop to about 65 percent; therefore,

$$t = \frac{6.459 \times 1{,}020 \times 4}{60{,}000 \times .65 \times 2} = .339 \text{ inch.}$$

Use ⅜-inch plate for this course.

For the fifth ring, the pressure is that due to a head of 10 feet of water, or $10 \times .433 = 4.33$; therefore,

This pressure is, therefore, small compared with the stress in the plates, due to the internal fluid pressure, so that the shell which has been figured to withstand the fluid pressure with a fairly large factor of safety will be sufficiently strong to support the weight of the tank. The force due to the weight of the tank acts in a vertical direction, while the force due to the fluid pressure acts in a horizontal direction. Therefore, the resultant of the two forces will be slightly larger than the force due to fluid pressure.

Make the width of plates in the five upper rings 60 inches between rivet lines. As the tank is to be 30 feet high over all, the width of the bottom ring will be something less than 60

inches, depending on the width of laps at the top and bottom of the tank. These will be determined when the size of rivets is determined. The length of plates between rivet lines may be made about 15 feet, as plates much larger would be difficult to handle in the shops, and small ones would necessitate an unnecessary number of vertical seams. As our tank is 85 feet in diameter, the circumference is about 267 feet; therefore, if each ring is made of eighteen plates, each plate will be about 14 or 15 feet long between rivet lines. Make the bottom ring an outside ring, then the mean diameter of the ring measured to the center of the thickness of the plate will be 85 feet 5/8 inch. The circumference corresponding to this will be $85.052 \times 12 \times 3.1416 = 3206.41$ inches. Dividing by 18 the length of one plate is found to be 178 1/8 inches.

The second ring will be an inside ring, and since the plates are 1/2 inch in thickness, the mean diameter will be 84 feet 11 1/2 inches. The circumference corresponding to this will be 3202.86 inches. Dividing by eighteen we find the length of one plate between rivet lines to be 177 15/16 inches.

The third ring will be an outside ring, and as the mean diameter is only slightly smaller than the mean diameter of the first ring, the length of the plates may be made the same as for the first ring. Similarly the length of the plates in the fourth ring may be made the same as the length of plates in the second ring. The mean diameter of the fifth ring is 85 feet 1/4 inch, making the length of one plate equal 178 1/16 inches. The mean diameter for the sixth ring is 84 feet 11 3/4 inches, making the length of one plate 177 31/32 inches.

For the vertical seams in the first ring, use 1-inch rivets. The pitch of the rivets may then be determined by making the strength of the net section of the plate equal to the strength of the rivets. The strength of the plate will be $t\ (p - d)\ Ts$. Calling S the shearing strength of rivets in pounds per square inch, the strength of rivets for a treble riveted lap joint will be $\frac{3}{4} \times 3.1416\ d^2\ S$. Assuming S equals 42,000 pounds per square inch or $.7\ Ts$, and equating the strength of plate to strength of rivets we have

$$t\ (p - d) \times Ts = \tfrac{3}{4} \times 3.1416\ d^2\ (.7\ Ts).$$

$$p = d + \frac{.75 \times 3.1416 \times .7\ d^2}{t}$$

$$p = d + \frac{1.65\ d^2}{t}$$

$p = 3.64$ inches, or 3 11/16 inches. The pitch of rivets for the vertical seams in the second and third rings will be found in a similar manner, using 7/8 rivets in each case.

As the vertical seams in the fourth ring are double riveted, the strength of rivets will be equal to $\frac{1}{2} \times 3.1416\ d^2 \times .7\ Ts$.

Therefore, $p = d + \dfrac{1.1\ d^2}{t}$

Using 3/4 rivets for the fourth ring, we find the pitch equals 2.4 inches. A slightly larger pitch might just as well be used and still have a perfectly tight joint. Increasing the pitch of the rivets simply means that the strength of the rivets is made less than the strength of the plate and that the joint will fail by the shearing of the rivets. Therefore, use 2 3/4 inch pitch for the fourth ring.

A similar calculation for the fifth and sixth rings, using 5/8-inch rivets gives 2.34 inches pitch. Use 2 3/8 for these seams.

As the stress in the shell in a vertical direction, due to the weight of the tank, has been found to be small, all circular seams may be single riveted except the lower edge of the first ring, which should be double riveted. By using the size of rivets ordinarily used with given thicknesses of plate and a sufficiently small pitch to insure a perfectly tight joint, sufficient strength will be obtained for these seams. As the thickness of the first ring is 5/8, use 7/8 rivets in the circular seams, using a 3-inch pitch in the lower double-riveted seam and a 2 5/8 pitch in the upper single-riveted seam; 7/8-inch rivets with a 2 5/8 pitch may be used for the second ring. The diameter of rivets for the top seam of the third ring may be reduced to 3/4 inch, and the pitch to about 2 1/2 inches. Beginning with the top seam of the fourth ring, 5/8-inch rivets spaced about 2 1/4 inches may be used in the remaining seams.

As the bottom of the tank is well supported, 1/4-inch plate may be used with single-riveted seams, 5/8-inch rivets. The plating will be laid in parallel rows using plates of as large size as possible, say, approximately, 6 feet wide by 15 feet long. This will give thirteen rows of plating, eleven of which are 78 3/4 inches wide between rivet lines, the two outer ones being 74 3/4 inches wide. A plan of the bottom may be laid out to a small scale, and the lengths of the seams scaled off the drawing, or the length of each seam may be calculated, since it is the chord of a circle whose distance from the center of the circle is known. For if R is the radius of the circle and S the distance of chord from the center of the circle, and L the length of the chord, then

$$(\tfrac{1}{2}\ L)^2 = (R + S)\ (R - S)$$
$$L = 2\sqrt{R^2 - S^2}$$

A template made to fit the arc of a circle 85 feet in diameter may be used to obtain the shape of the ends of the outside plates, two points in the curve having been found, viz., the ends of the seams. The butt joints of adjacent plates should never come together. The plan, Fig. 1, shows the arrangement of these plates.

It still remains to lay out the angle-bars which join the shell and bottom, and also the angle-bars which are placed around the top edge of the tanks as stiffeners. As there is to be a double row of 7/8-inch rivets in each leg of the bottom angle, at least a 6-inch angle should be used, and as the lower shell plates are 5/8 inch, the angle should be at least 5/8 inch thick. The length of a 6 inch by 6 inch by 5/8 inch inside angle bent to an outside diameter of 85 feet, may be found as follows:

If D = outside diameter of ring,
W = width of angle,
t = thickness of angle,

then the length of the ring before bending will be $3.1416\ [D - (1/3\ W + t)]$. Therefore, the length of the bar will be

3.1416 [85 × 12 — (6/3 + .625)] = 3196.18″ or 266.4′. The ring may be made of nine bars, each bar 29.6 feet long.

Using a 4-inch by 4-inch by $\frac{5}{8}$-inch bar around the top edge of the tank the length of the ring before bending, since it is an outside ring, will be 3.1416 [85 × 12 + 4/3 + .625], which equals 3211.58″ or 267.63′. This ring may also be made of nine bars, making the length of each bar 29.74 feet.

Having determined the sizes of the plates and angles for the tank, the bill of material may be tabulated as follows:

BILL OF MATERIAL FOR I-TANK.

Mark.	No. Required.	Description.
W 1	39	Plates, $\frac{1}{4}$″x81″x191$\frac{1}{4}$″.
W 2	2	" $\frac{1}{4}$″x Sketch.
W 3	2	" $\frac{1}{4}$″x "
W 4	4	" $\frac{1}{4}$″x "
W 5	2	" $\frac{1}{4}$″x "
W 6	2	" $\frac{1}{4}$″x "
W 7	4	" $\frac{1}{4}$″x "
W 8	4	" $\frac{1}{4}$″x "
W 9	4	" $\frac{1}{4}$″x "
W10	4	" $\frac{1}{4}$″x "
W11	18	" $\frac{5}{8}$″x58$\frac{3}{8}$″x186$\frac{3}{8}$″.
W12	18	" $\frac{1}{2}$″x62$\frac{3}{4}$″x185$\frac{3}{4}$″.
W13	18	" $\frac{7}{16}$″x62$\frac{5}{8}$″x185$\frac{7}{8}$″.
W14	18	" $\frac{3}{8}$″x62$\frac{3}{8}$″x182$\frac{5}{8}$″.
W15	18	" $\frac{1}{4}$″x62$\frac{1}{4}$″x182$\frac{5}{16}$″.
W16	18	" $\frac{1}{4}$″x62$\frac{1}{4}$″x182$\frac{1}{4}$″.
W17	9	Angles, 6″ x 6″ x$\frac{5}{8}$″x30′ 0″.
W18	9	" 4″ x 4″ x$\frac{5}{8}$″x30′ 0″.
W19	9	Plates, $\frac{3}{16}$″x12$\frac{3}{16}$″x2′ 0″.
W20	9	" $\frac{3}{8}$″x 6$\frac{3}{8}$″ x2′ 0″.
W21	2	30′ Sections of std. ladder.
W22	2	12″x18″ Saddle Plates, Manheads, arches, bolts, cranes, etc., complete.
C 1	1	20″ C. I. Gland and calking strip.
C 2	1	16″ C. I. Gland and calking strip.
C 3	2	8″ C. I. Gland and calking strip.

BILL OF RIVETS FOR I-TANK.

Mark.	No. Required.	Description.					
R23	1000	Rivets,	1″	diam.	x 2$\frac{1}{2}$″	Cone	Heads.
R24	75	"	$\frac{7}{8}$″	"	x 3$\frac{1}{4}$″	"	"
R25	300	"	$\frac{7}{8}$″	"	x 3″	"	"
R26	150	"	$\frac{7}{8}$″	"	x 2$\frac{1}{2}$″	"	"
R27	2300	"	$\frac{7}{8}$″	"	x 2$\frac{3}{8}$″	"	"
R28	1200	"	$\frac{7}{8}$″	"	x 2$\frac{1}{4}$″	"	"
R29	1250	"	$\frac{7}{8}$″	"	x 2$\frac{1}{8}$″	"	"
R30	4600	"	$\frac{7}{8}$″	"	x 2″	"	"
R31	150	"	$\frac{3}{4}$″	"	x 2$\frac{1}{2}$″	"	"
R32	1450	"	$\frac{3}{4}$″	"	x 1$\frac{7}{8}$″	"	"
R33	800	"	$\frac{3}{4}$″	"	x 1$\frac{3}{4}$″	"	"
R34	50	"	$\frac{5}{8}$″	"	x 2$\frac{1}{8}$″	"	"
R35	100	"	$\frac{5}{8}$″	"	x 2″	"	"
R36	800	"	$\frac{5}{8}$″	"	x 1$\frac{7}{8}$″	"	"
R37	250	"	$\frac{5}{8}$″	"	x 1$\frac{3}{4}$″	"	"
R38	1500	"	$\frac{5}{8}$″	"	x 1$\frac{5}{8}$″	"	"
R39	9500	"	$\frac{5}{8}$″	"	x 1$\frac{1}{2}$″	"	"

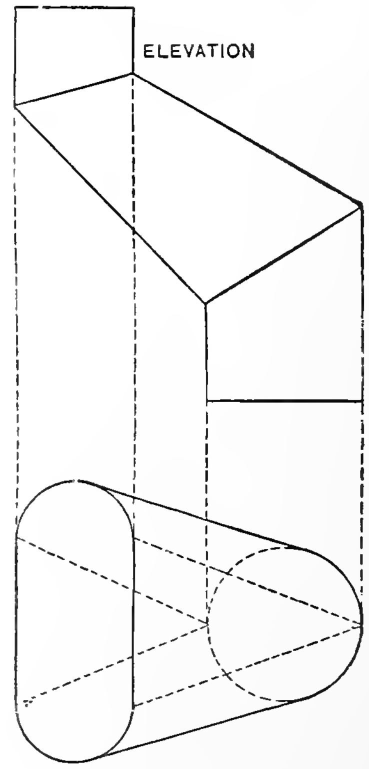
The outside edges of the shell and the inside edges of the bottom should be marked for calking, and the corners of the plates, which come between two other plates, should be marked for scarfing; also the manholes and location of pipe flanges should be indicated, as shown on the drawing, Fig. 1.

The capacity of the tank in gallons may be found as follows: Find the area of the bottom of the tank in square feet, multiply it by the height of the tank in feet, and multiply the product by 7.481, the number of gallons in a cubic foot.

$$\frac{3.1416 \times (85)^2 \times 30 \times 7.481}{4} = 1{,}273{,}530 \text{ gallons.}$$

The Layout of an Offset from a Round to an Oblong Pipe.

The plan and elevation of the offset are shown in Fig. 1. It will be seen that this problem requires three separate patterns, and that while two of them may easily be obtained by



PLAN

FIG. 1.

orthographic projection, the third must be developed by triangulation.

In Fig. 2 is shown the method of solving this problem when both halves are symmetrical. First draw the elevation of the offset as shown by *A B C*. On *C*, place the half-section of the round pipe, as shown in *E*, and on *A* the half section of the oblong pipe, as shown by *D*. Divide the semi-circles in both half-sections into equal spaces, and number *E* from 1 to 5, and *D* from 6 to 12. From these figures in *E* and *D* draw lines parallel to the lines of the pipes intersecting the miter lines in *C* and *A*, respectively, as shown from 1 to 5 and 6 to 12 in *B*. Connect these figures with solid and dotted lines, as shown, which represent the bases of sections which will be constructed in *K* and *M*, whose altitudes are equal to the various heights in the semi-sections in *D* and *E*.

For example, to obtain the true length of the line 9-3 in *B*, take this distance and place it on any line in *K*, as shown by 9′ 3′, from which points erect perpendiculars 9′ 9 and 3′ 3, equal, respectively, to the distance measured from the line 12 6 to point 9 in *D* and the distance measured from the line 1 5 to point 3 in *E*. Then will the distance 9 3 in *K* be the true

length of 9 3 in *B*. Proceed in this manner for all the true solid lines shown in *K*, and the true dotted lines shown in *M*, all indicated by similar numbers.

Before the pattern is developed for *B*, the half patterns for *A* and *c* are developed as follows: Obtain the girth of the half section *D* and place it on the line 6' 12, extended as shown from 6' to 12'. Draw the usual measuring lines which are intersected by lines drawn parallel to 6 12 from similar numbered intersections on the miter line between *A* and *B*. Trace the miter cut *H J*; then will *J* 12' 6' *H* be the half pattern for the oblong pipe *A*. For the half pattern for the round pipe *C*, place the girth of the semi-section *E* upon the line 1' 5' extended, as shown by 1 to 5, from which points the usual measuring lines are drawn and intersected by lines drawn parallel to 1' 5' from similar numbered intersections on the miter line between *B* and *C*. Through points thus obtained trace the miter cut *F G*. Then will *F G* 5' 1' be the required half pattern.

Now, having the true length in the sections *K* and *M* and the true lengths along the miter cuts *G F* and *H J*, the pattern for the transmission piece *B* is developed as follows: Assuming that the seam will come on 1 12 in *B*, take the distance of 5 6 in *B* and place it on the horizontal line 5 6 in *S*. Now, with 6 7 in the half section *D* as a radius and 6 in *S* as a center, describe the arc 7, which is intersected by an arc struck from 5 as a center and 5' 7 in *K* as a radius. As the dotted line runs from 7 to 4 in *B*, then take the true lengths of 7 4 in *M*, and with 7 in *S* as a center describe the arc 4, which intersect by an arc struck from 5 as a center and 5 4 in the miter cut *G F* as radius. Now, with 7 8 in the miter cut *H J* as radius and 7 in *S* as center, describe the arc 8, which intersect by an arc, struck from 4 as center, with the true length 4 8 in *K* as radius. Proceed in this manner using alternately first the division in the miter cut, *F G*, then the true length in *M*; the division in the miter cut *H J*, then the true length in *K* until the line 1 11 in *S* has been obtained. Then with 11 12 in the half-section *D*, or the miter-cut *H J* as radius, and 11 in *S* as center, draw the arc 12, which intersect by another arc struck from 1 as center and 1 12 in *B* as radius. Trace a line through the points thus obtained in *S* as shown by 1, 5, 6, 12, which will be the half pattern. Trace this half pattern opposite the line 5 6, as shown by 5, 1°, 12°, 11°, 7°, 6, and the full pattern is completed. The laps and other allowances must, of course, be added to this pattern.

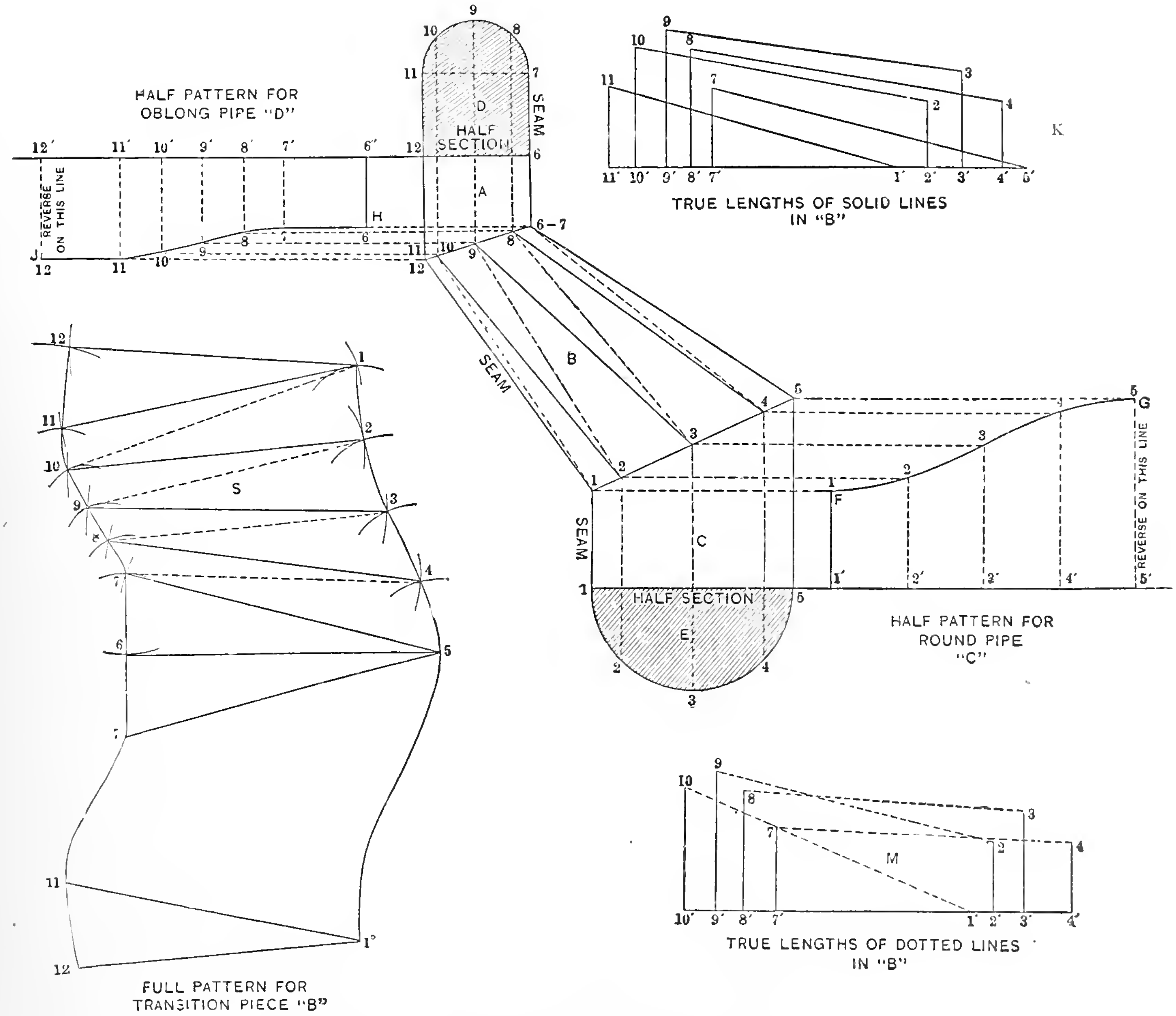


FIG. 2.

The Lay Out of a Four-Piece 90-Degree Elbow with Large and Small Ends on Each Course.

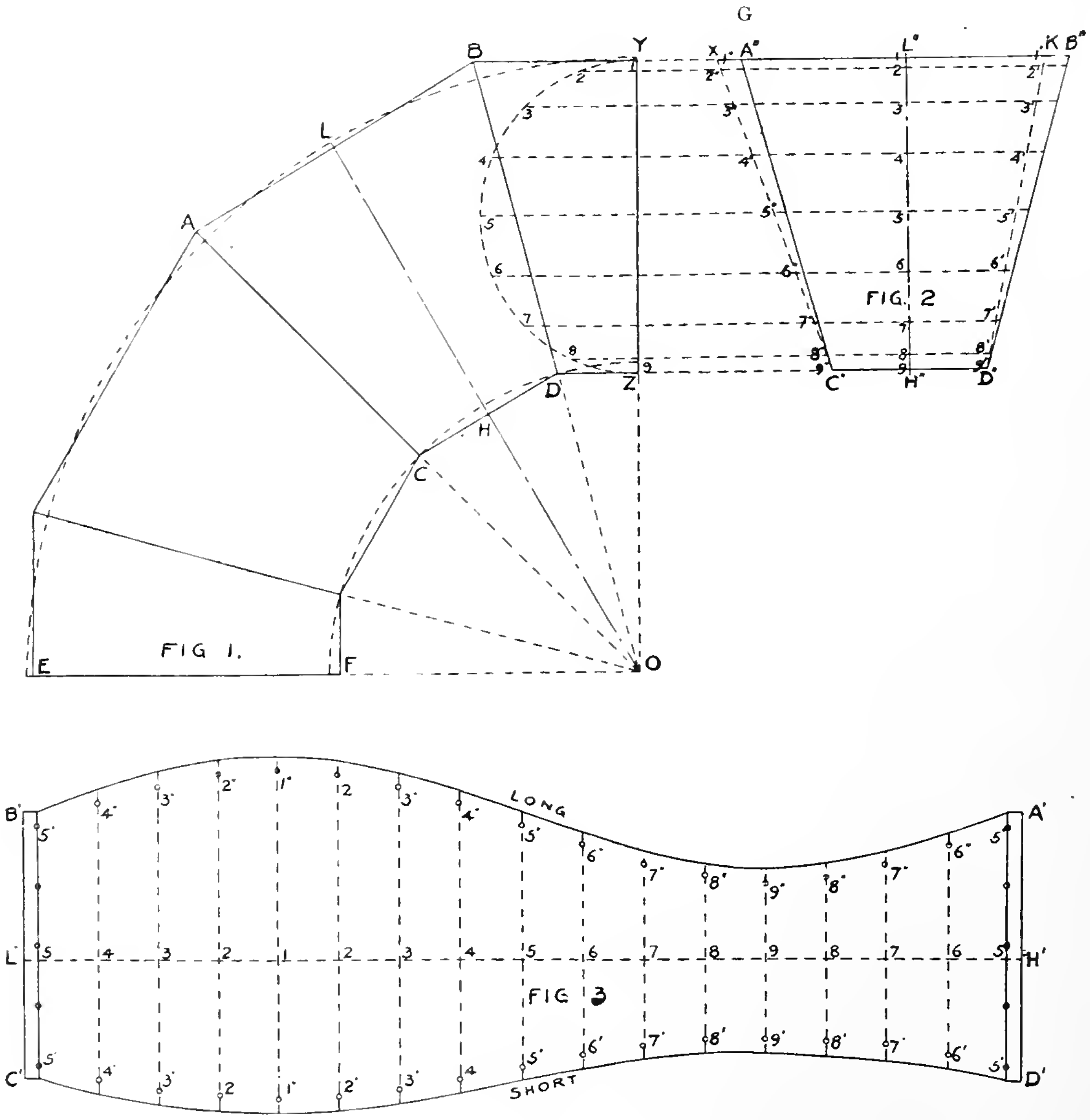
Draw the lines EO and YO, Fig. 1: then with O as a center and with the trammels set to a length of 12 inches, draw the quarter circle FCZ. With the same center and with the trammels set to a length of 24 inches, draw the quarter circle EAY. Divide the quarter circles FCZ and EAY, respectively, into six equal parts. Draw lines from C to D, A to O and B to O. Also draw the line LO through the point H perpendicular to CD. Where the line CD intersects LO, lay off a distance of 12 inches to the point L. Draw the line AB through the point L parallel with CD.

The course $ABCD$ is all that is required for the pattern. Therefore transfer $ABCD$, Fig. 1, to A'' B'' C'' D'', Fig. 2. Describe a semi-circle on the line YZ and divide it into eight equal parts. Draw horizontal lines from the points 1, 2, 3, 4, 5, 6, 7, 8 and 9, Fig. 1, extending them until they intersect the line B'' D'', Fig. 2. On the line B'' A'' mark K 1 inch from B. Draw the line KD'', and then lay off from A'' the distance A'' X equal to 1 inch. Draw the line XC''; then the measurements for the development, Fig. 3, should be taken from these lines KD'' and XC'', Fig. 2.

To obtain the distance XA'' run the line C'' A'' some distance above the line XB'' and then set the dividers with one leg on A'' and with a radius equal to twice the thickness of the iron locate a point G. Then, with one leg of the dividers on C'' and a radius equal to C'' G, draw the arc intersecting XB'' at X. Then with one leg of the dividers on B'' and a radius equal to A'' X draw an arc to the point K.

Draw the line L' H', Fig. 3, 38 inches long, and divide it into sixteen equal parts. Draw lines through these points of division at right angles to L' H'. Mark these lines with the same numbers as were used for the corresponding points, Figs. 1 and 2. Measure the distance from 1-1″, Fig. 2, and transfer it to 1-1″, Fig. 3. In a like manner transfer the distances 2-2″, 3-3″ 4-4″, etc., to Fig. 3. Having completed the pattern on one side of L' H', transfer the distances 1-1′, 2-2′ 3-3′, 4-4′, etc., Fig. 2, to the corresponding lines in Fig. 3. The points thus located are to be punched for rivets. Add the lap outside these points and the pattern is completed.

The development shows that the line A' B', Fig. 3, is longer than the line C' D', thus showing how the large and small ends are obtained. Two pieces of stock will, therefore, be needed for the pattern A' B' C' D', one piece for A' B' L' H' and one piece for C' D' L' H'. The figures given for this layout are for 14-gage iron. A sheet 30 inches by 39 inches will make the elbow without waste. An elbow of any size can be laid out for any size iron by making the necessary allowance at B'' K and A'' X, Fig. 2.

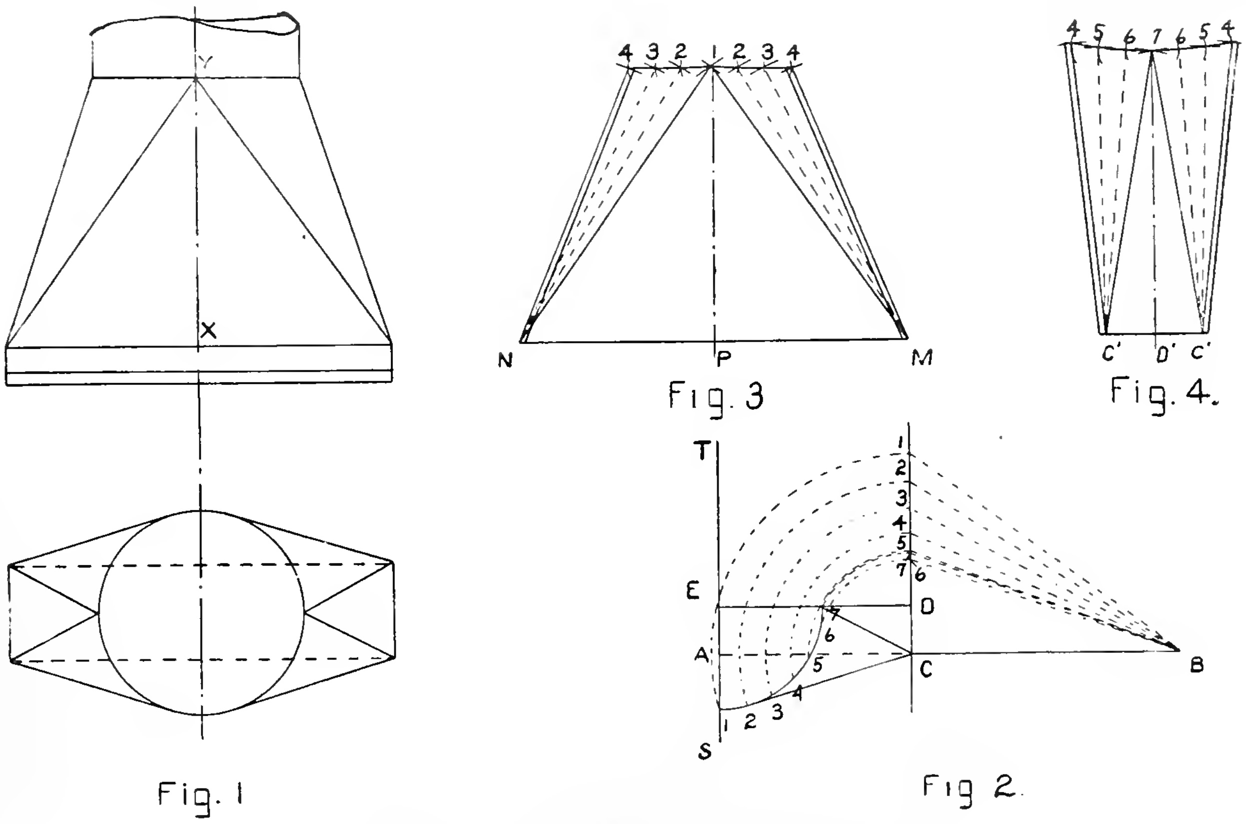


LAYOUT OF FOUR-PIECE 90-DEGREE ELBOW.

Layout of the Bottom Course of a Stack.

It will be seen from the plan and elevation, Fig. 1, that the course is round at the top and rectangular at the bottom. First draw the line *ST*, Fig. 2, and at any convenient point, as *E*, draw the line *ED* at right angles to it. With *E* as the center, and a radius equal to the radius of the stack, draw the quarter circle and divide it into as many equal spaces as there are in the quarter circumference of the stack, marking each point as shown by the figures 1, 2, 3, 4, etc. Lay off from the points *E* and *D* half the width of the base of the stack, locating the line *AC*. Make *ED* and *AC* equal in length strike the arcs 2, 2 intersecting those which were made from the points *M* and D. Do the same with the rest of the points until point 4 is reached; then the lines *N*4 and *M*4 would locate the rivet lines for the sides of this sheet. As the plate is bent, however, on the lines 1*N* and 1*M*, it will be seen that this would bring a rivet hole on the sharp corner; to avoid this, draw the rivet lines as shown about ¾ inch in toward the center line but parallel respectively to the lines 4*N* and 4*M*.

For the side patterns, shown in Fig. 4, set the trams to the distance *DC*, Fig. 2, and with *D'*, Fig. 4, as a center locate the points *C' C'*. Center punch these points and with the trams



PATTERNS FOR BOTTOM COURSE OF STACK.

to half the length of the base; thus making the figure *EDC*1 a quarter plan. Lay a straight edge on the points *C* and *D*, and draw the line *CD*, extending it indefinitely, as shown, then with the trams set from the point *C* to the points 1, 2, 3, 4, etc., on the quarter circle describes the arcs shown dotted until they interesect the line *CD* at points 1, 2, 3, 4, etc. Extend the line *AC* to *B*, making *CB* equal to *XY*, Fig. 1, the height of the course. Connect the point *B* with the points 1, 2, 3, 4, 5, 6 and 7; then the lines *B*1, *B*2, *B*3, etc., will be the true lengths of the lines drawn from *C* to the points 1, 2, 3, 4, etc., in the plan view.

As the course is to be made in four sections, lay out first the front or back section, shown in Fig. 3. Draw a line on the sheet at a distance from the edge equal to the distance at which the rivet holes are to be located from the edge of the plate; then set the trams to the distance *AC*, Fig. 2, and with *P* as a center locate the joints *M* and *N*. Center punch these points and set the trams to the line *B*1, Fig. 2, and with the points *M* and *N*, Fig. 3, as centers, strike the arcs intersecting at 1. The center line may then be drawn from 1 to *P*. Again, set the trams to the line *B*2, Fig. 2, and with *M* and *N*, as centers, strike the arcs 2, 2. With the dividers set to the distance 1-2 on the quarter circle, Fig. 2, and with 1 (Fig. 3) as a center set to the distance *B* 7, Fig. 2, and the points *C' C'*, Fig. 4, as centers, strike arcs intersecting at 7. Then reset the trams to the distance *B*6, Fig. 2, and with the points *C' C'*, Fig. 4, as centers strike the arcs 6, 6. Also with the dividers set to the space 6-7 on the quarter circle, Fig. 2, and with point 7, Fig. 4, as a center, strike the arcs 6, 6 interesecting the arcs previously drawn. In a similar way locate the points 5 and 4, Fig. 4; then the lines *C'*4 would be the rivet lines for these two sets of patterns. Since, however, the rivet holes in Fig. 3 were located ¾ inch in towards the center from the lines *M*4 and *N*4, in order to match, the rivet lines in the side patterns, Fig. 4, should be located ¾ inch outside the lines *C'*4, as shown by the solid lines parallel to the lines 4*C'*.

It seems to the writer that the diagram, Fig. 2, for developing the parts of the patterns which must be laid out by triangulation saves considerable time, as the whole thing is laid down together and cannot easily be lost sight of.

Any problem in triangulation is simple if care is taken to avoid confusing the various construction lines used in the solution of the problem, and that has been the special object in each step of the preceding problem. The patterns might have been divided in a different way, bringing the seams in a different position, without changing the method of solution.

Explanation of a Simple Method of Laying Out Ship Ventilating Cowls.

In designing a group of cowls for a vessel, the visual effect should be taken into consideration, as well as utility, as it costs no more to make a well-shaped cowl than it does to make a poor one.

In the annexed sketches are presented a group of six cowls, and a very simple method of determining their outlines from the diameters of their bases, and the development of the patterns for their construction. In Fig. 3, the group of cowls is shown, ranging from 4 inches to 14 inches diameter of the center line of the cowl will be found, and an equal distance between the points H and A, will give the centers for a corresponding curve below the center line. Extending the line of the axial plane through the cowl, the points of intersection with the perpendicular line through the center of the base will give the base line of the cowl, with a proportional amount of straight part to receive the usual fittings. In Fig. 3 the line of the axial plane cuts the center of the base of each cowl.

In laying out a group of cowls for a ship, first establish the axial plane from the largest cowl in the series. From this

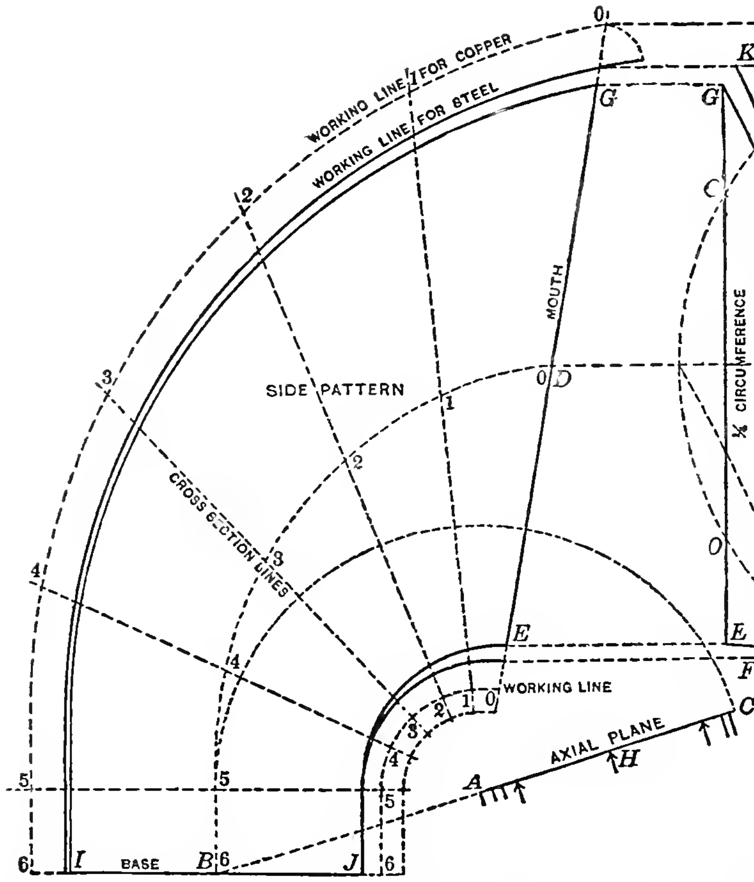


FIG. 1.—SIDE VIEW OF COWL, SHOWING METHOD OF OBTAINING THE SIDE PATTERNS.

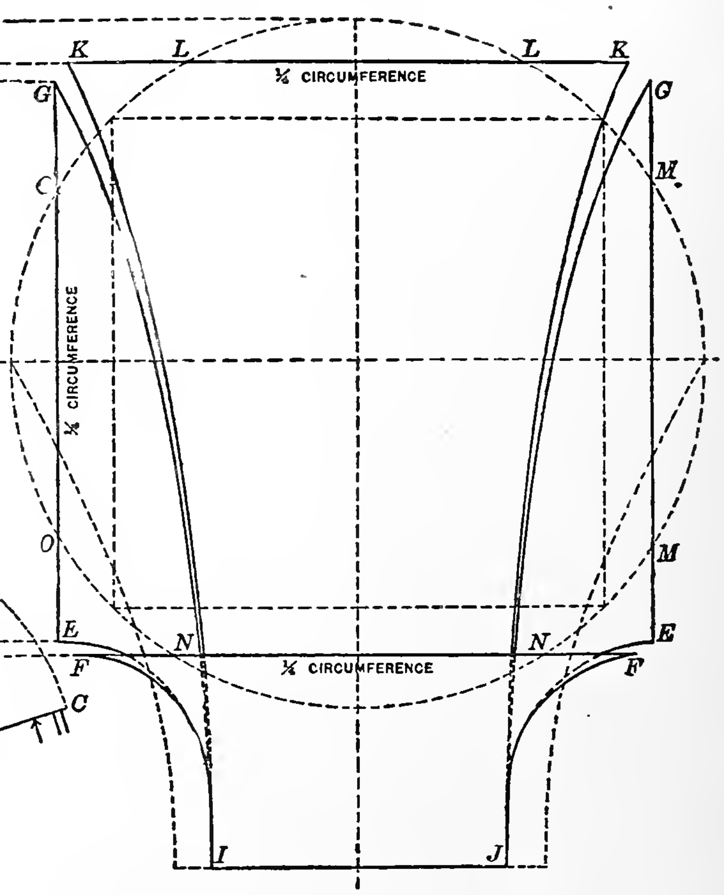


FIG. 2.—FRONT VIEW OF COWL, SHOWING THE WORKING POINTS IN THE PATTERN SHEET.

base. It can be readily seen that their curves and diameters have a relative proportion to each other. In Fig. 4 is shown the method of obtaining the outlines from the diameter of the base. The throat line is first determined, its radius being taken as one-fourth the diameter of the base. Thus the cowl in Fig. 5 is 14 inches in diameter at the base, and the radius of the throat is 3½ inches. This is the largest cowl of the group shown in Fig. 3. In developing the further outline, draw in the throat and project a line parallel to the base, as from E to C. With A as a center, draw an arc tangent to the perpendicular line through the center of the base and cutting the horizontal line at C. This point of intersection is the center for the curve of the back or crown. Draw a line from A to C, which forms the axial plane, upon which will be found the centers of the different radii required in developing the outlines, or the patterns of the sheets to form them. Bisect the axial plane and you obtain the point H; this is the center of radius for a curve that will pass through the center of the cowl from the base to the mouth. Between the points H and C the centers for all the curves used above plane the others can be developed, and so they will have a relative proportion. In developing the patterns for an axial seamed cowl, as represented in Figs. 8 and 9, mark off on the base and mouth of the cowl the points IJ and EG, Fig. 1, which should equal one-fourth of the circumference of their respective diameters. Draw the curved lines from E to J, and from G to I; this gives the pattern for the sides. The center of radius for these curves is found on the axial plane.

To obtain the pattern for the back and throat pieces, divide the center line through the side pattern into any number of equal parts, and from the center of radius of throat, draw the cross-sectional lines through the side pattern, which will give one-fourth of the circumference of the cowl at these points. Extend these lines until they cut the curve of the back, and the curved working line at the throat numbered 1, 2, 3, 4 and 5. Transfer these divisions as they occur to the straight lines SU and TV, Figs. 5 and 6. Draw lines through these points of divisions at right-angles to the lines SU and TV, and make them correspond to the length of the cross-sectional lines in the side pattern. With a light wooden batten sprung along

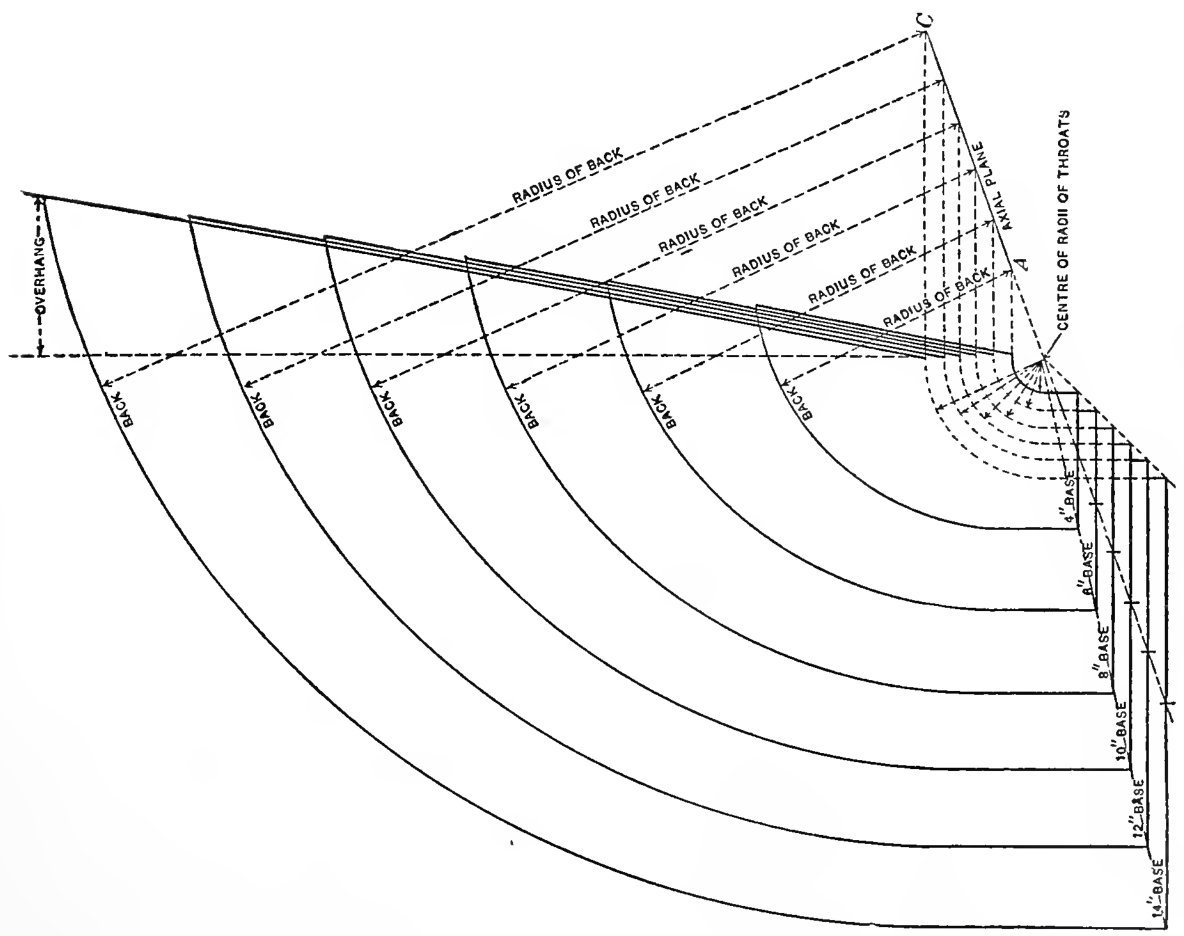


FIG. 3.—GROUP OF SIX COWLS.

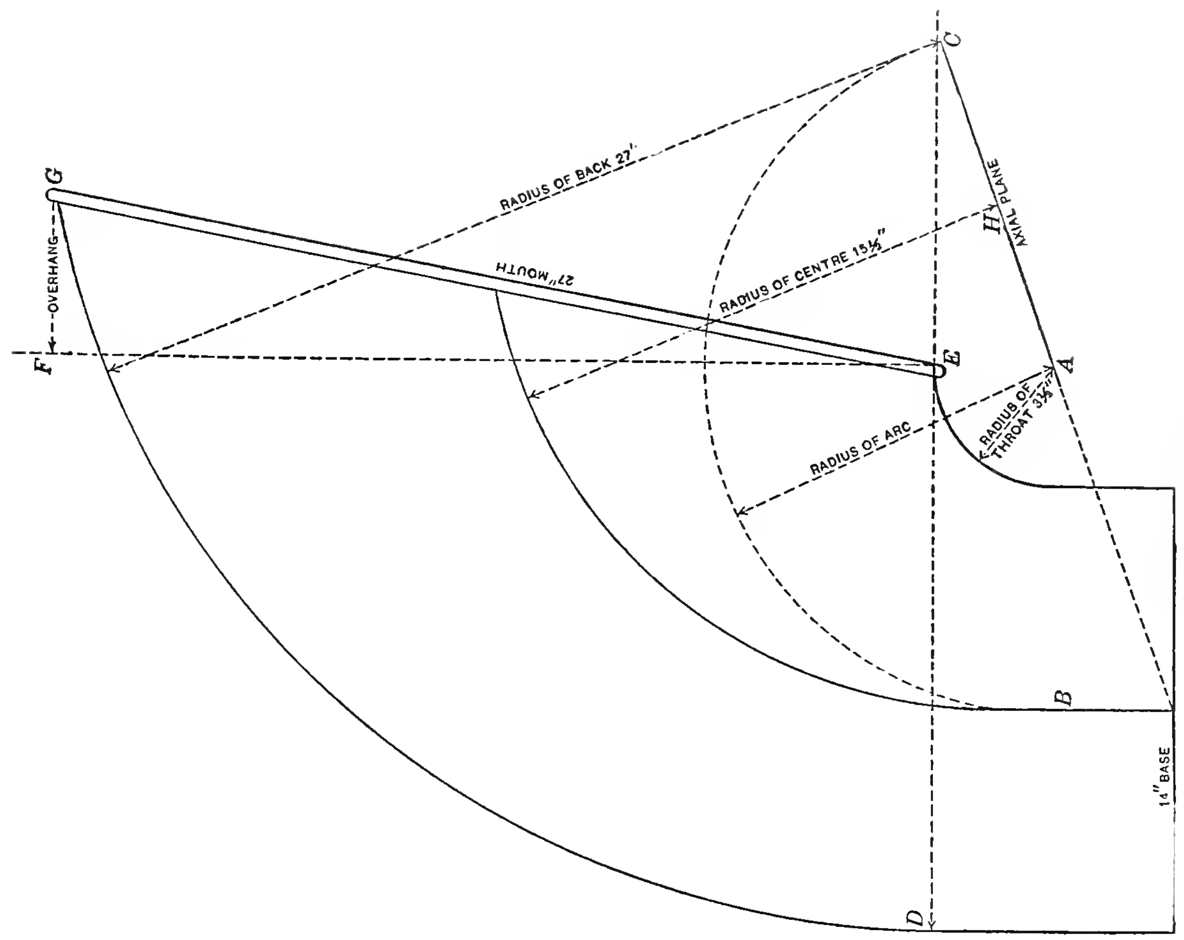
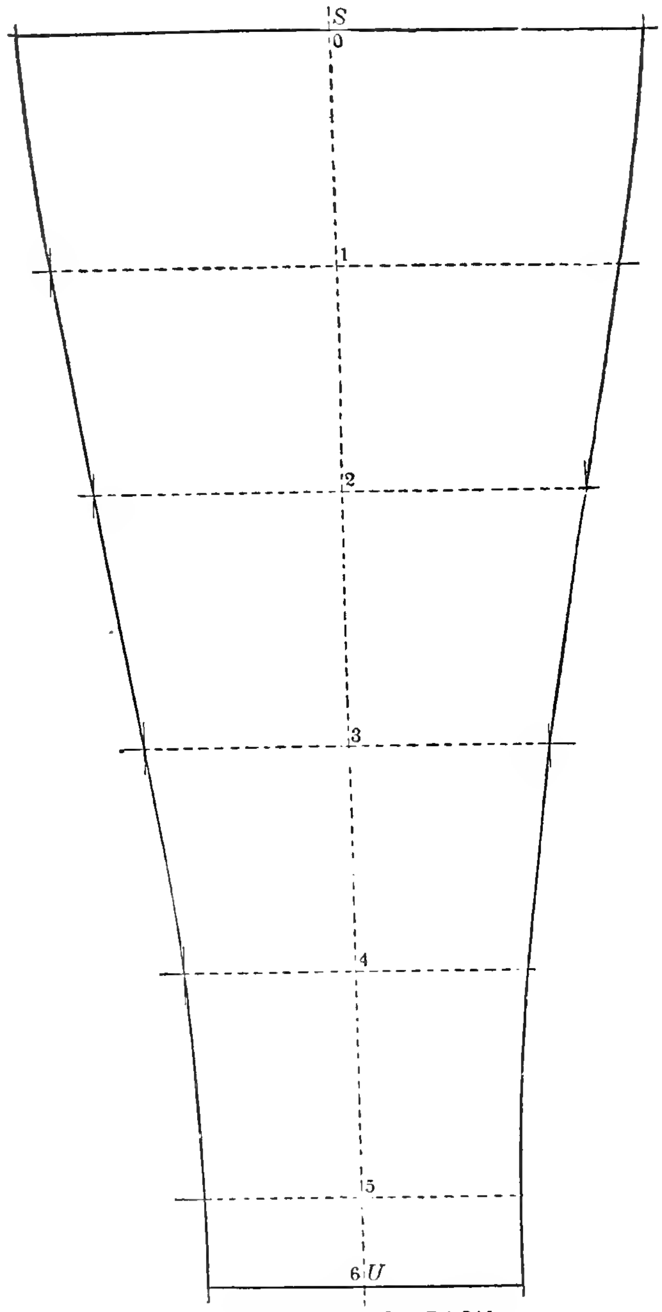


FIG. 4.—METHOD OF DEVELOPING OUTLINES.

the extremities of these lines, draw the outlines of the patterns for throat and back. In Fig. 2, the dotted lines give the front view of the cowl. The solid lines show the edges of the pattern sheets in the flat before being worked into shape, and on the working lines.

In making the cowls of planished iron or steel, the back



PATTERN FOR BACK.
FIG. 5.

and side sheets are worked down in the center on a hollow block between the points *LL*, *MM* and *OO*. In working down the centers, the edges of the sweep will rise to the sweep. The edges of the throat-piece are peened to the sweep of the curve and the center filled out afterwards. The four pieces are then rounded up and planished on suitable heads, fitted together, riveted, and a finishing bead put on the edge.

Fig. 7 shows the front view of the throat piece worked into shape. This is the most difficult to make, and care is required in its manipulation. In making the cowls of sheet copper, very little work is is performed before brazing. The pattern sheets of the throat and back are bent to the working lines, as shown in Fig. 3, the edges are worked over about 1 inch to meet the side pattern and then scarfed. The edges of the side patterns are then scarfed and cramps cut to receive the back and throat pieces, as shown in Fig. 9. They are then fitted together and brazed. After the seams are dressed the cowl is then rounded up and planished on suitable mandrels and heads.

The finishing bead on the edge of the mouth of the cowl is made of a split tube, and is bent to shape around a wooden sweep, the radius of the mouth, with a strip of metal in the slit to keep it from closing and also to keep the slit in the center.

This method of making cowls is very flexible. The cowls

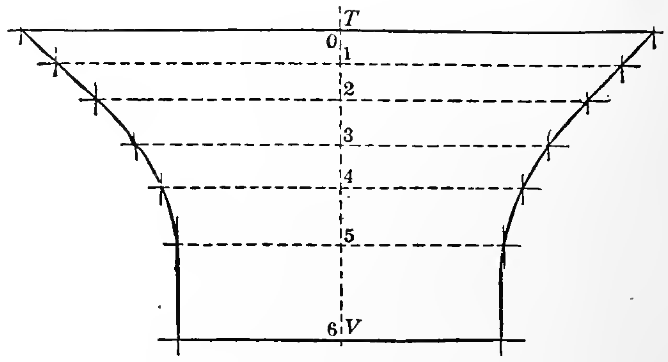


FIG. 6.—PATTERN FOR THROAT.

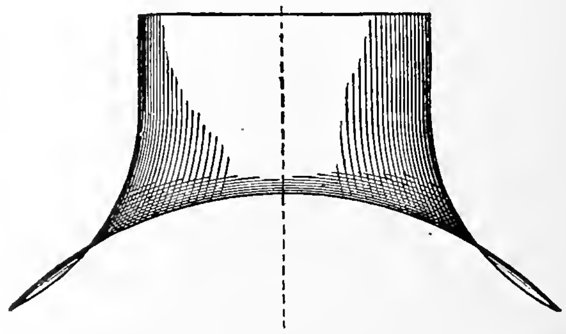


FIG. 7.—FRONT VIEW OF THROAT WORKED TO SHAPE.

may be proportioned to suit the judgment of the designer, or the requirements of a case, by simply altering the pitch of the axial plane. The principal features in this method, which will recommend its use, are: The simplicity of development of the outlines and patterns, the absence of cross-sectional seams, a uniform thickness of metal throughout the cowl, and the saving of time, labor and material. A cowl made from this method does not look as though it had been constructed from the scrap heap, but gives a finished appearance well worth trying for in an up-to-date steam vessel.

Developing a Cylinder Intersecting an Elbow by the Method of Projection.

Though this method involves a large amount of work, the result gained more than compensates for the time taken to execute the drawing, for it shows step by step how and why the plan is divided into equal spaces, which in turn by extending lines develops the pattern. If you take some particular numbered point on the plan and follow the line from that point up to the miter line of the elbow, thence out to the development to the same numbered line, you will readily see how that particular point is secured on the development, but

for the benefit of the uninitiated we will proceed to explain step by step. First, erect the perpendicular line 6 from the bottom plan to 6 on the top plan, then draw center line of the angle you wish to make the elbow, in the drawing it is 120 degrees from the horizontal line R_1-R_2-R_3 to R_{11}, extend the dotted lines R_1 and R_{11} until they intersect at X, these lines being at right angles to the center lines of the elbow, with X as a center draw arc R_1 to R_{11} also arcs on center line and inside line of the elbow. Space the arc R_1 to R_{11} into six equal spaces, set off on the arc one-half of a single space, and from that point step off five full spaces and

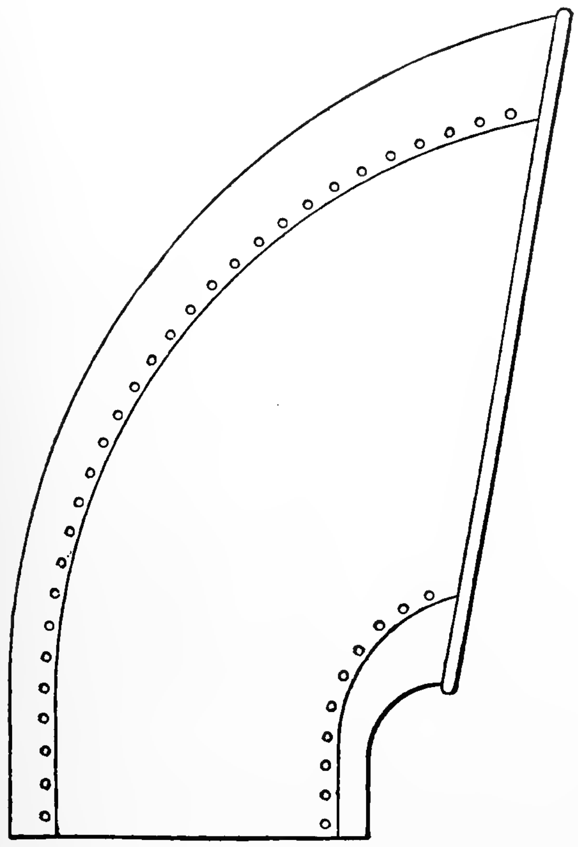


FIG. 8.—FINISHED COWL IN FOUR PIECES, STEEL.

from the last point spaced, the distance to R_{11} should be the other half of the single space, this makes a seven-pieced elbow, but virtually comprised of six full sections, as Sec. A and Sec. G are one-half sections, from these points secured on the arc draw lines to the common radial center X, these lines constitute the miter lines of the seven pieces of the elbow viz., A, B, C, D, E, F, then draw bottom line of Sec. A parallel to R_1, R_3; directly below this draw a one-half plan of the elbow and divide into equal spaces; from these points draw lines up to miter line of Sec. A and B, extend these lines through the several sections B, C, D, E, F, G, making Sec. G the same length as Sec. A, the points I, J, K, L, showing a half section of a full section. Now draw the side lines (1 and 11) of the cylinder H, with line 6 being the center of the cylinder, also draw directly above the half plan of H and space into equal parts; in order to get the true intersection of the cylinder H with the elbow, it is necessary to have a cross-section, which is shown as B^2, C^2 and D^2. We will first proceed with B^2; extend the outside line 11 of B any suitable distance clear of the elevation, then draw the line 1 to C of B^2 at right angles to the extension of line 11 of B, then with Ra, Y of the bottom plan as radius, set this distance from A to C on B^2, and with C as a center, swing the arc A, B, C, D, E, F, G, and with ½ of the top plan of H, 6 to 11, draw this ¼ circle to the left of the line 1 to C, space this into equal spaces same as top plan and number 1 to 6; drop lines parallel to 1, C down to arc which gives you points on arc of A, B, C, D, E, F, from these points extend lines parallel to A to Sec. B, then draw lines from top plan of H down to where they intersect lines from B^2, as you will see by the drawing the lines 5 and 6 of H do not run into Sec. B, but drop on to Sec. C, likewise lines from E, F, of B^2 are not extended

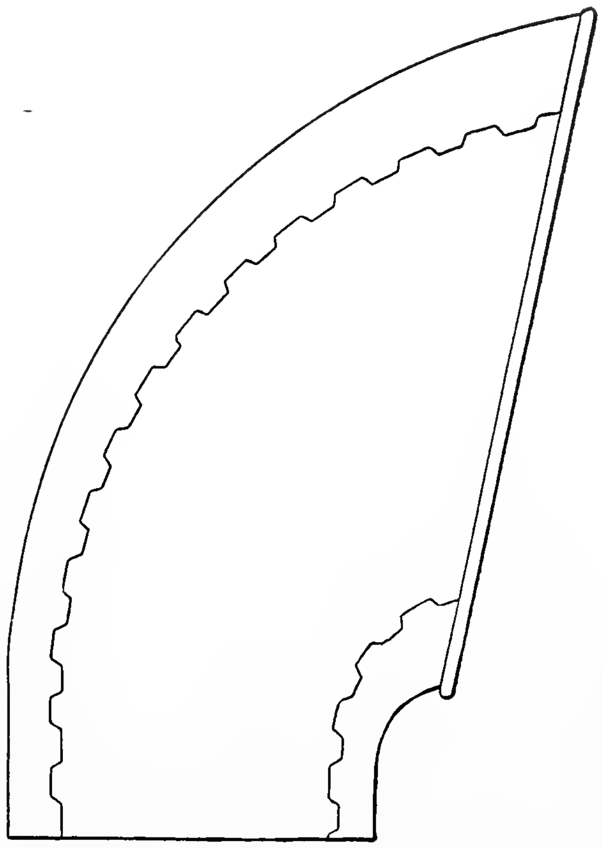
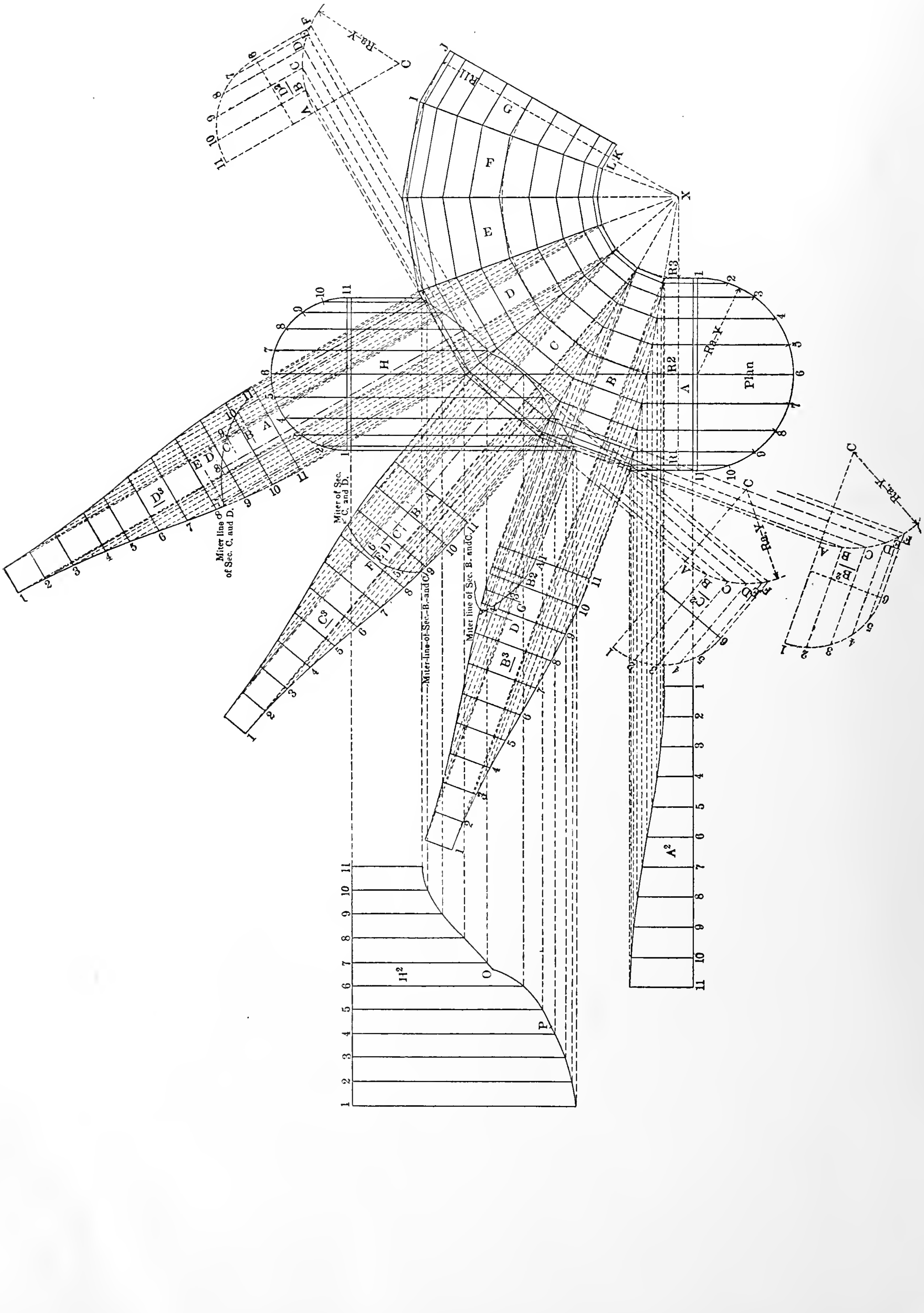


FIG. 9.—FINISHED COWL IN FOUR PIECES, COPPER.

through to B. It is not necessary to make as many of the cross-sections as shown, but was done, as it gives a better understanding, for by so doing you can more easily see what points require extending to meet the corresponding numbered lines from H. For instance, line 6 does not fall on Sec. D, therefore it is useless to extend it from F of D_2. The cross-sections C^2 and D^2 are shown in the same manner; always make the line to point A an extension of line 11 of the elbow. As will be seen by the drawings, all developments are one-half of the circumference; B^3, C^3 and D^3 showing the full half with the line of intersection of H shown thereon as marked by the numbers corresponding to the cross-section.

The section A is secured by drawing the line 1 to 11, (A^2) at right angles to line 11 of A, the spacing on A^2 being the same as on bottom plan, the several points from 1 to 11 on miter line of Sec. A to B are drawn parallel to the base line and produced to meet the perpendiculars from the correspondingly numbered spacing line on A^2, then drawing a line through these several points gives you ½ the development of A.

To secure B^3 draw lines at right angles to the lines 1 to 11



SIDE ELEVATION AND PATTERNS FOR A CYLINDER INTERSECTING AN ELBOW.

of B, where those cross the miter lines of Secs. A to B and B to C, extend these lines until they meet the correspondingly numbered spacing lines 1 to 11 of B^3, then draw a free hand line through the several points and that development is ½ the circumference of B. To secure the intersection of the cylinder H on B, first take the distance on B^2, from A to B, B to C and C to D, set off and draw lines parallel to line 11 of B^3, then extend lines from the points on B of 1, 2, 3, 4, that intersect lines from B^2 of A, B, C, D, until they meet lines on B^3 of A, B, C, D. You will notice that line of intersection of H on B crosses the miter line between 8 and 9; to secure this point on B^3 draw a line from that point on miter line up to B^3, which comes on the developed line between 8 and 9, draw a line from that point through the intersections of D, C, B, A and you have the intersection line of cylinder H on Sec. B. Proceed in same manner with Sec. C and D.

The cylinder H^2 is secured similarly to A^2, the points O and P being the points where the cylinder comes on miter lines of B to C and C to D.

By taking a single point on plan such as 5, and following it up to the miter line on B, thence out to 5 on B^3 you will see that all points and lines are relative to each other; likewise take 8 from plan of cylinder H, follow it down to D, thence out to D^3, then go back to D^2, point 8 down to the arc point D and on to D, thence out to H^2 and it brings you out on line 8, (H^2).

Developing the Pattern for a Copper Converter Hood Having a Round Top and an Irregular Base.

First draw the end elevation Fig. 1, then draw the side elevation Fig. 2; from these two elevations you will be able to obtain the dimensions of the plan Fig. 3. In this plan all measurements of circles are taken from the center of the iron. On the elevations Fig. 1 and Fig. 2, let the center line of Fig. 1 extend downward indefinitely, and at right angles to this line draw the line A B C, Fig. 3, and on this line lay off the points a and b, Fig. 1, holding B as center. As the top of the hood is to be round, take a B as radius, and B as center, and strike the semi-circle a D b, which will give the plan of the top.

Next in order will be to lay down the lines on the plan which will form the base of the top plates which lap over the lower sections of the hood. This will not be a true circle, as will be seen. Transfer the points c and d, Fig. 1, to the line A B C, Fig. 3; also transfer the length of the line E F, Fig. 2, and mark it on the center line of the plan from B to E, Fig. 2, this being one-half the elevation of the side view of the hood. Draw in to find the length of the major axis of the portions of the eclipses used in this work. It will be seen that the half of this article to the left of the center line (Fig. 3) is made elliptical in shape at the base; therefore all intermediate points between the round top and the base would also be elliptical. The length of the major axis is taken from Fig. 2, and the minor axis from Fig. 1, while the portion to the right is circular in all respects. Each circular division being struck from a different center, B is only the center of the semicircle a D b, while the arc E d of the plan is struck from another center; E c is a portion of an eclipse made by arcs of different circles.

Next in order will be to lay down the plan of the top and bottom of the lower sections of the hood which can be done in the same way that the plan was done for the top plates.

Transferring the points e f, Fig. 1, to the line A B C, Fig. 3, also transfer the length of the line G H, Fig. 2, and mark the length from B to G, Fig. 3. The points e G will be the two points on which to construct the portion of the ellipse, while G f will be the two points on which to construct the portion of a circle or arc, whose center will be located on the line A B C, which will complete the plan of the top of the lower section.

The plan of the base will be constructed in the very same manner, and needs no further explanation.

Now that we have the plan and elevation, all that remains to be done is to construct the triangles, the bases of which will be found on the plan Fig. 3, and the altitude of the different triangles will be found in the elevation. To construct these triangles it will be necessary to divide the line g I h of the plan into a number of parts, these parts can be equal or unequal, as it makes no difference; so in this case we will divide it into equal spaces, because a sketch so small can be better worked out that way. Divide g I into five spaces, and I h into six spaces; from these points, 1, 2, 3, etc., draw solid lines to the point B or center of the semicircle at the top. These solid lines will be the true length of the bases of the different triangles to be constructed, that is, the distance on each from the line c E d to the semi-circle a D b will be the bases of the triangles for the lower part of the hood. The distance from the line c E d to the semicircle a D b will be the basis of the triangles on the solid lines for the top part of the hood.

In order to complete the bases of the triangles it will be necessary to construct another set of bases which are distinguished by dotted lines and lettered a, b, c, etc., in italic letters. These bases, it will be seen, run diagonally across the spaces made by the solid lines and join No. 1, solid line, to No. 2, solid line, also No. 2 to No. 3, etc., which completes the bases of the triangles. Now it will be necessary to construct the altitude of the triangles. In the top plate the altitude is the same for all. In the lower plate they will all be different lengths, and may be obtained in this way. From the points established on the line g I h, Fig. 3, draw lines parallel to the center line I B, up till they cut the base of the hood or the shell of the converter, Fig. 1; at these points draw lines at right angles to the center line I B indefinitely to the right and left and number them according to the point drawn from in Fig. 3.—1, 2, 3, etc. The distances from J to the different lines on the center line, Fig. 4, will be the altitude of the triangles to be constructed. Then transfer the solid base lines No. 1, Fig. 3, to the same lines on the elevation, Fig. 1, using the junction of the base lines and the center line as the right angle corner of the triangles. A line drawn from this point to J will be the hypotenuse of that triangle; then transfer the solid lines No. 2, of Fig. 3, to the same number on Fig. 1, also on this same line, transfer the length of the dotted line a. A line drawn in from these points to J will be the hypotenuse of these triangles and the true length on the lines for the pattern. All the rest of the lines in the lower part of

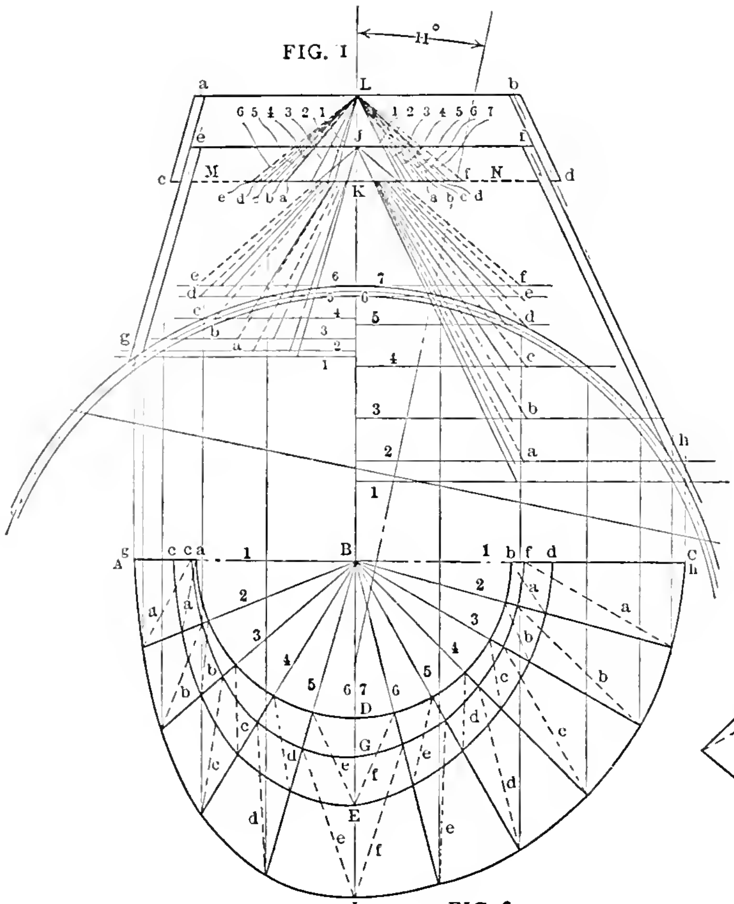


FIG. 1

FIG. 3

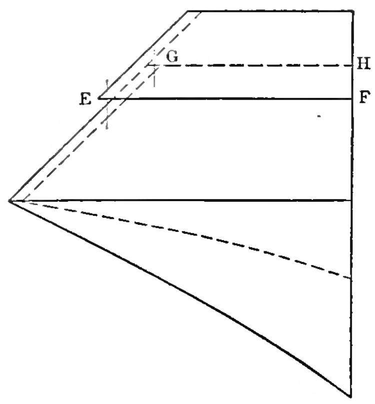


FIG. 2

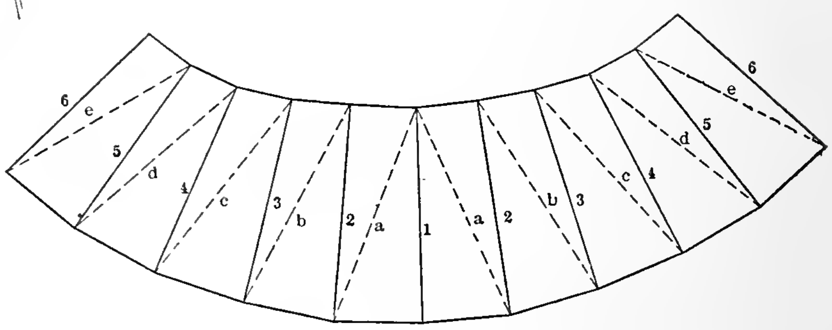


FIG. 7

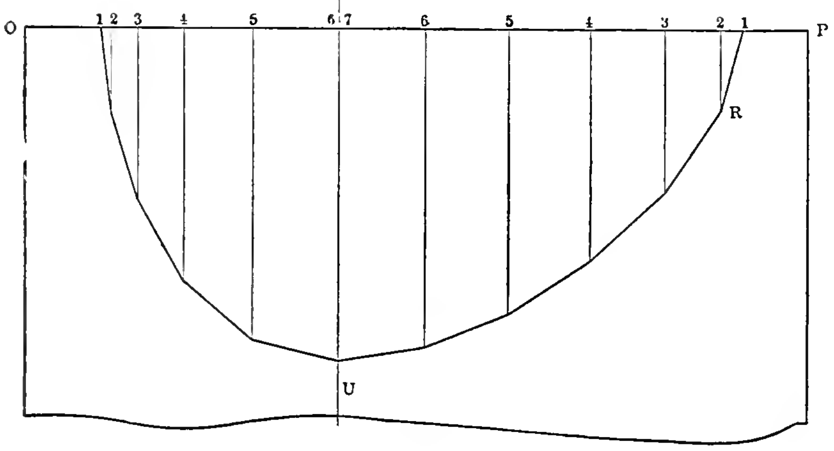


FIG. 4

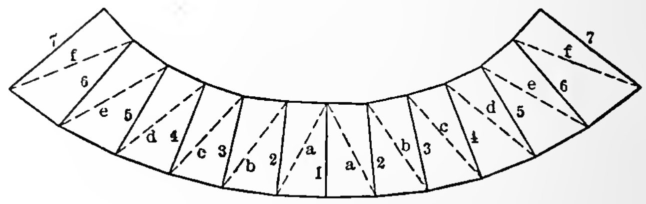
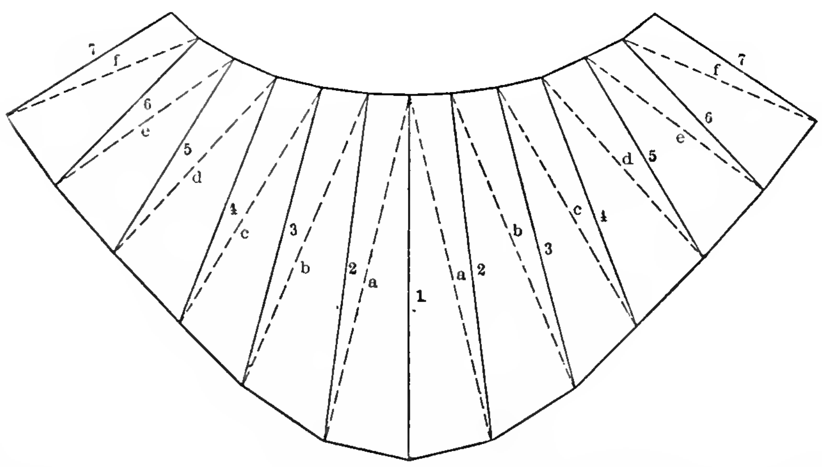


FIG. 6



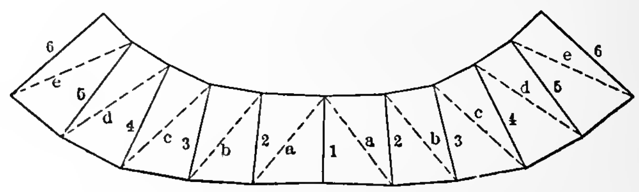


FIG. 8

PATTERNS FOR A COPPER CONVERTER HOOD.

the hood will be obtained in the same way, and need no further explanation.

The triangles in the top plate which form Fig. 6 and Fig. 8 on the pattern are somewhat easier to obtain, as the altitudes of these triangles are all of one length, that of *L K*, Fig. 1.

Transfer the solid lines No. 1 between the lines *a D b* and *c E d* to the line *M N*, and mark them to the right and left of *K*, in Fig. 1, and by this system set up a series of triangles of both solid and dotted lines No. 1, 2, 3, etc., and *a, b, c,* etc. Now the triangles are complete. All the triangles at the right go to make up the plates Fig. 5 and Fig. 6, while those to the left will make up Fig. 7 and Fig. 8.

You will notice that the spaces between the points on line *g I h*, Fig. 3, are not the correct spaces to be used in developing the pattern, as they are much too short, on account of the hood setting on a convexed surface, therefore, it will be necessary to draw an extended view of the base of the hood.

In other words lay out the hole, which will be cut or punched in the top section of the shell, and to which the hood joins. From the edge of this take the spaces which form the lower edge of the plates or the flange line. This will give the correct spacing between the solid and dotted lines at that part of the hood.

To lay out the hole, a correct stretch-out of the line from *g* to *h*, Fig. 1, at the center of the shell must be obtained and laid off on line *O P*, Fig. 4. Take the distance from the point where the center line of the hood intersects the center line of the shell to the point where the line at the left intersects the center line of the shell. Mark it to the right of the center line on Fig. 4, which is marked 5, the center line being 6 and 7 on the right side; transfer the rest of these points in the same manner. From these points on the line *O P*, Fig. 4, draw lines at right angles from the points 1, 2, 3, etc., right and left, and upon these lines transfer the length of the vertical lines in Fig. 3, from where they intersect the line *A B C* to where they intersect the circular line *g I h*, which is the base line of the plan. Whatever the distance is from *B I*, Fig. 3, mark it on the line 6 and 7, Fig. 4, which establishes the point *U*, and the center line of the hole. Also transfer the rest in like manner. This done, join the joints together by straight lines. These lines or distances will be the true length of the bases of the triangles used to lay out Fig. 5 and Fig. 7, or the lower plates of the hood. They will also give the cut-out of the hole, or one-half of the hole in the top of the convertor. The other half will be a duplicate of it, and from the cut-out the proper allowance can be made for the rivet holes in the plate by which the flange will be marked off after being fitted to the shell.

To lay out the plate, Fig. 5, take the length of the hypotenuse line No. 1, at the right on Fig. 1, the lower part of the hood, and place this line at any convenient place on the plate Fig. 5 and mark its length; then set the trammels with distance from No. 1, Fig. 4, to *R*, and with this distance as radius, and with the lower end of the No. 1 line, Fig. 5, as center, make an arc cutting the arcs made by the dotted line *A*, and from the intersecting points of the arcs draw lines to the lower end of the No. 1 line, and from the intersecting points draw the dotted line to the top of the solid line No. 1. This will give two of the triangles used in the plate. To obtain the next triangle, set the trammels with the distance between the solid lines 1 and 2, which will be found on the line *e G f* at the right of Fig. 3, and with this distance as radius, and the upper end of the No. 1 line, Fig. 5, as center, cut arcs to the right and left of the line No. 1; then take the length of the solid hypotenuse line No. 2, Fig. 1, and with this as radius, and the lower end of the lines *a*, Fig. 5, as center, draw arcs cutting the arcs at the right and left of line 1; this will give four of the triangles used in this plate, and the remainder need no further explanation. Fig. 7 will be made in the same way by using the line at the left of the center line in Figs. 1, 3 and 4. Next we will take up Fig. 6, which is the top piece of the hood and must lap over the top of Fig. 5, and for which we must use the hypotenuse line at the right, also in Fig. 1, but in the uppper part of the figure; first take the length of the solid line No. 1, Fig. 1, and place it on the plate Fig. 6, which is the center line and is the altitude of two triangles whose bases are taken from the plan Fig. 3, between the lines 1 and 2, on the line *c E d;* with this distance as radius, and the lower end of No. 1 line, Fig. 6, as center, scribe an arc at the right and left of the No. 1 line, then take the length of the dotted line *a*, top of Fig. 1, and with this distance as radius, and with the top of the No. 1 line, Fig. 6, as center, scribe arcs cutting the arcs made by the radius struck from the other end of the line; joining these points will give two of the triangles in this plate. To obtain the next, take the distance between the lines 1 and 2, Fig. 3, on the circular line *a D b*, at the right, and with this distance as a radius, scribe arcs to the right and left of line 1, Fig. 6, at the upper end of line. Then take the length of the solid line 2, Fig. 1, and with that distance as radius, and the lower end of the dotted line *a*, Fig. 6, as center, scribe arcs cutting the arcs to the right and left of line 1; this will give four of the triangles in plate 6; the rest can be obtained in the same way.

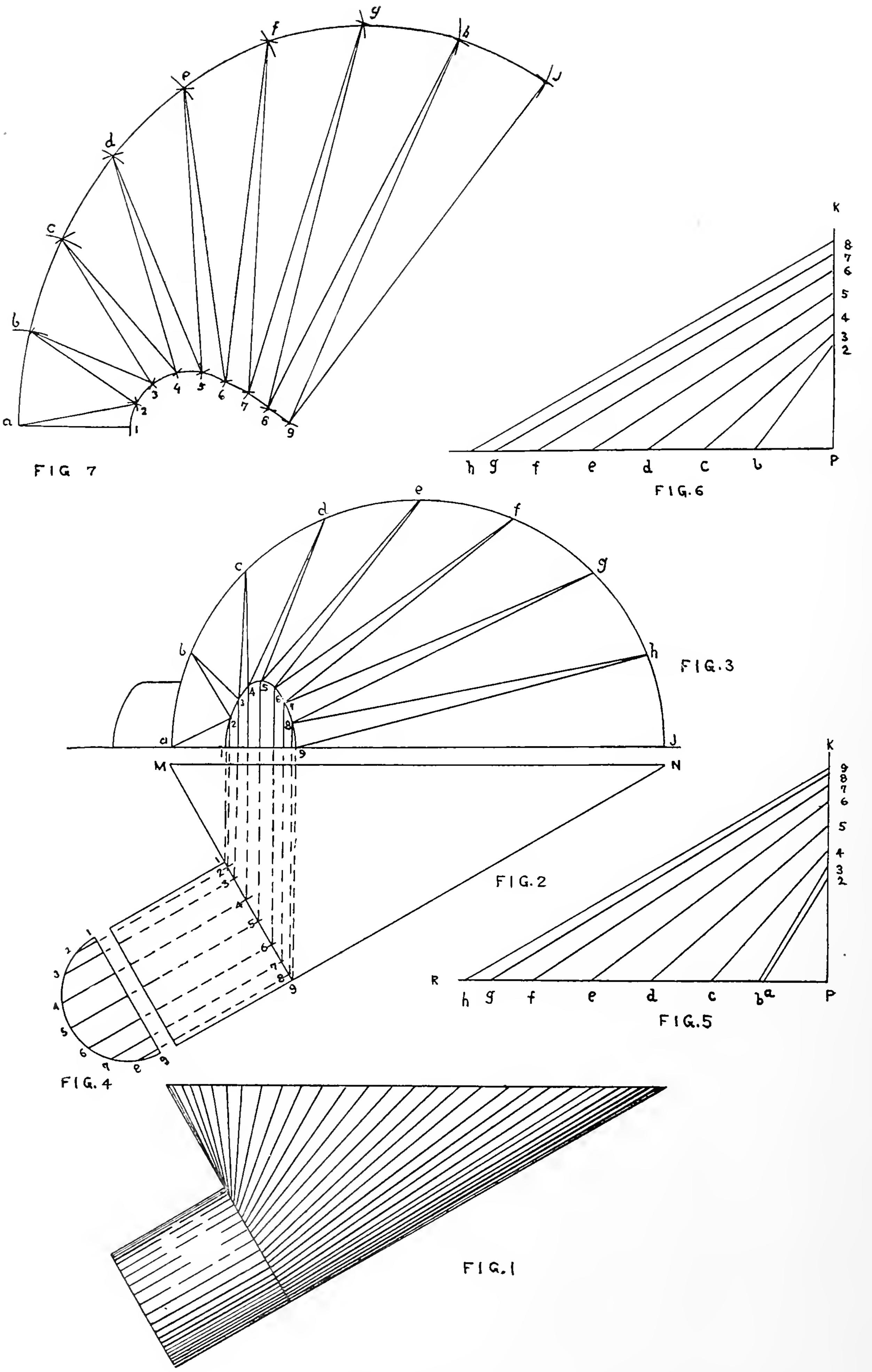
Fig. 8 can be constructed by using the hypotenuse of the triangles at the left in Fig. 1 as altitudes, and the spaces on the line *a D b* and *c E d*, Fig. 3, as bases outside of the line given here. Allowances must be made for flange at the base of hood, also rivet holes for laps and butt straps.

By making more spaces in the plan you will of course make more triangles, and in this way you will be able to overcome the irregularities on the pattern, such as the corners left by the different angles of the triangles.

Laying Out a Hopper for a Coal Chute by the Method of Triangulation.

The hopper and chute to be laid out are shown shaded in Fig. 1. The conditions are: that the mouth of the hopper shall be round, 4 feet 6 inches diameter, that the distance on the side where the chute joins it should be 12 inches from the edge of the hopper to the chute, that the angle formed by this intersection should be 90°, and that the after side of the hopper should lay parallel with the chute, the chute to be round, 12 inches in diameter.

The practical considerations are how to lay out the hopper so as to make the least work in connecting the chute to it



LAYOUT OF A HOPPER FOR A COAL CHUTE.

This may be done in several ways, but we shall make it as shown in the drawing with the joint parallel to the short side of the hopper, so that the end of the chute which joins the hopper should be *only* a straight cut. By this method very little flanging will be required, and it can be easily riveted.

In the accompanying illustrations it will be noted that similar figures and letters denote similar joints or lines.

Fig. 1 is a shaded view of the hopper and chute.

Fig. 2 is a side view of same.

Fig. 3 is a top or plan view of half the hopper.

Fig. 4 is a view of half the end of the chute.

Fig. 5 is a set of triangles, of which the lines a2, b3, c4, d5, e6, f7, g8, h9, Fig. 3, are the bases; these lines or distances are taken from Fig. 3 and set off on the line P. R., Fig. 5, from the point P. The verticals of these triangles are taken from Fig. 2, from the line M N (which is the upper edge of the hopper), downward to the line of the joint, as 1, 2, 3, etc. They are set off upward, on the line P K, Fig. 5, as from P to 2, 3, 4, etc., the lines P R and P K form a right angle, and the points 2, 3, 4, etc., on P R are connected to the joints a, b, c, etc., on the line PR. We now have right angle triangles, the slant side or hypotenuses of which we desire to obtain.

It will be noticed that there are two sets of lines on Fig. 3, one set running from the letters on the edge or rim of the hopper inward to the edge of hole, as a2, b3, c4, etc., and another from the edge of the hole outward to the edge of the hopper, as 2b, 3c, 4d, etc.; for this second set of lines we must also have a set of triangles; these are shown in Fig. 6; these were also constructed for the purpose of obtaining their hypotenuses, using the same heights as in Fig. 5.

Now to determine the points, 1, 2, 3, 4, 5, 6, 7, 8, 9 on Figs. 2 and 3: make the drawing as shown in Figs. 2, 3 and 4, divide the circles into an equal number of spaces and mark them as a, b, c, d, e, f, g, h, j, Fig. 3, and 1, 2, 3, 4, 5, 6, 7, 8, 9, Fig. 4, the number in this case is eight, but when the experimental pattern to determine the correctness of the rule was made only four were used.

Having done this, transfer these points from the half circle in the direction of the dotted lines from Fig. 4 to the joint line, Fig. 2, and from there vertically upward to Fig. 3, making a solid line on Fig. 3 as a continuation of the dotted lines (in reality the dotted lines are not needed in laying out the work, they were put here only for the purpose of showing the direction in which the points are to be transferred.)

The points 1 and 9 are established on Fig. 3 by the intersection of the lines 1 and 9 with the line A J, but the points 2, 3, 4, 5, 6, 7, 8 are taken from Fig. 4, as, for instance, we take the length of the solid line 2 from Fig. 4. and set it off on the solid line 2 on Fig. 3 from the line A J, and the line 3, Fig. 4, to the line 3, Fig. 3, from A J, and so on, until they are all taken off from Fig. 4 and set on their corresponding lines on Fig. 3, and the points so established when connected with a curved line form the edge of the hole for the chute. Now connect these points with the points b, c, d, e, f, g, h on the edge of the hopper, forming triangles as shown.

Having completed these operations we are now ready to lay out the pattern of the hopper, the half of which is shown in Fig. 7. Draw a line, any length, long enough on which to lay off the distance a1, take this distance, which is from M 1, Fig. 2, then from Fig. 4, on the circle, take the distance 1-2, and from the point 1, on a1, Fig. 7, and at right angles to a1, describe an arc, then take the distance a, b, Fig. 3, and from the points a, on line a1, Fig. 7, describe an arc. Then from Fig. 5 take the hypotenuse a2, and from the point a on a1, Fig. 7, cut the arc 2, establishing the point 2. Then from Fig. 6 take the hypotenuse 2b, and from the point 2, Fig. 7, describe an arc cutting the arc b, connect these points with lines, and it will be seen that we have laid out a section of the pattern composed of two triangles, formed by the points 1a2 and a2b. Then we start over again and lay out the adjoining section 2c3 and c3d. Take from Fig. 4 the distance 2 3 on the circle and set it off on Fig. 7 from the point 2, describing an arc, then take the distance b c from Fig. 3 and set it off from the point b, Fig. 7, describing an arc. Now, from Fig. 5 take the hypotenuse b3 and set it off from the point b, Fig. 7, cutting the arc 3, and from Fig. 6 take the hypotenuse 3c and set it off from the point 3, Fig. 7, cutting the arc C. Connect these points with lines and we have another section. Continue this process until the point 9 is established and the distance h J has been set off, then from the point 9, Fig. 7, cut the arc J. Connect 9J with a line and also connect all the points a, b, c, d, e, f, g, h, and 1, 2, 3, 4, 5, 6, 7, 8, 9 with curved lines, and we have half the pattern but without laps, and the lines 9J and 1a are the center lines.

Now, if it is desired to make the hopper in one piece, and you are laying it out directly on the sheet you are going to use, it will only be necessary to work the laying out of the other half backwards. Allow half the lap on the outside of a1 on each end. If it is desired to flange the hopper into the pipe, the flange must be allowed; if the pipe goes into the hopper, then allow the flange on the pipe.

By this method it will be seen that it is not necessary to lay out a special pattern for the pipe, as it would be if the joint was made at an angle to the side.

Pattern of a 90-Degree Tapering Elbow.

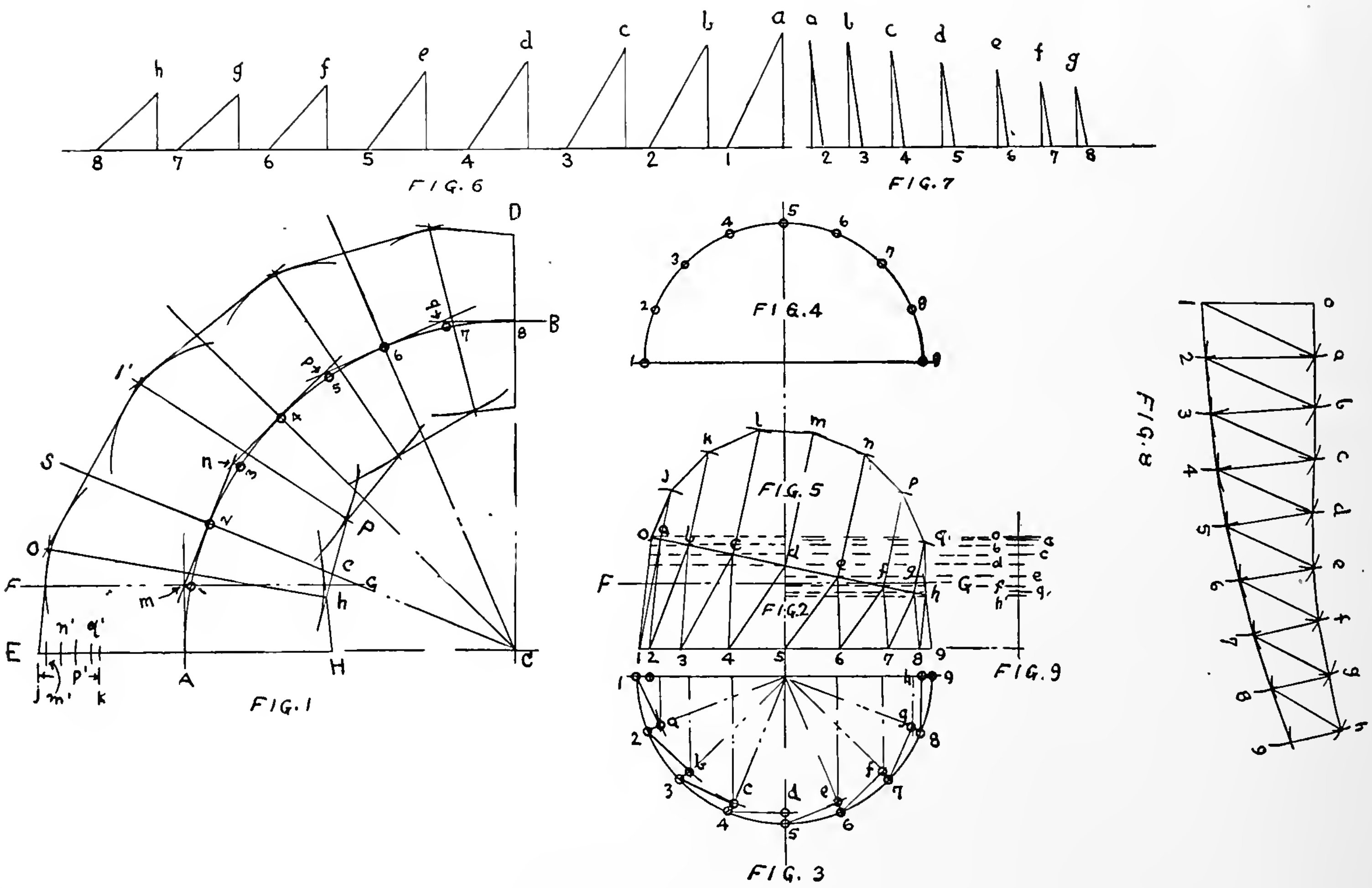
As will be seen, the patterns of this elbow have been developed by the method known as triangulation, as it requires less room to work it than it does by the method of conic sections; as, for instance, if the large end were 36 inches diameter and the small 30 inches, and each half section 10 inches long, from the center line making the whole length 80 inches, the radius would be a little over 40 feet, and if the taper was less than 6 inches, the radius would be proportionately larger, and in either case not very easy to handle; whereas, in the case of triangulation, all the preliminary work can be done on the drawing board, making the drawings to a scale, and when taking off the different lengths to lay down the pattern, multiply their lengths by the scale.

Fig. 1 is a side elevation and is constructed as patterns. Lay off a right angle *ECD*, and from the point *C* as a center, strike a quarter of a circle *AB*, with a radius required for the center of the elbow. Determine the number of sections you want in the elbow and multiply by two. This elbow is made

in four sections, three whole and two half, and is known as a four-section elbow. There should always be a half section at each end, otherwise you would have to miter the end of the connecting pipe to the end section.

As above stated, this is a four-section elbow and $4 \times 2 = 8$; then divide the quarter circle into eight equal parts, as 1, 2, 3, 4, etc. After having done this, draw lines from *C* through the points 2, 4, 6. On these points, at right angles to the radial lines and tangent to the circle, draw straight lines of an indefinite length, intersecting each other at *MNPQ*. Then on the line *CE*, set off the half diameter of the large end on each joints of the intersection of these lines at the back and in the throat with lines, the different sections of the elbow are defined. The side elevation is complete and the final shape and correct dimensions are determined.

Now, prepare for the development of the pattern of the large end, but in order not to get too many lines piled on top of one another, make a separate drawing of this end section, as shown in Fig. 2. Within the points 1, *O*, *h*, 9, continue the center line far enough above and below the figure so as to be able to lay Figs. 3 and 4 on it. Then below Fig. 2, draw a horizontal line 1, 9, Fig. 3, and from its intersection with the



PATTERN FOR END SECTION OF A 90-DEGREE TAPERING ELBOW.

side of the center *A*, and on the line *CD*, set off the half diameter of the small end on each side of the center *B*.

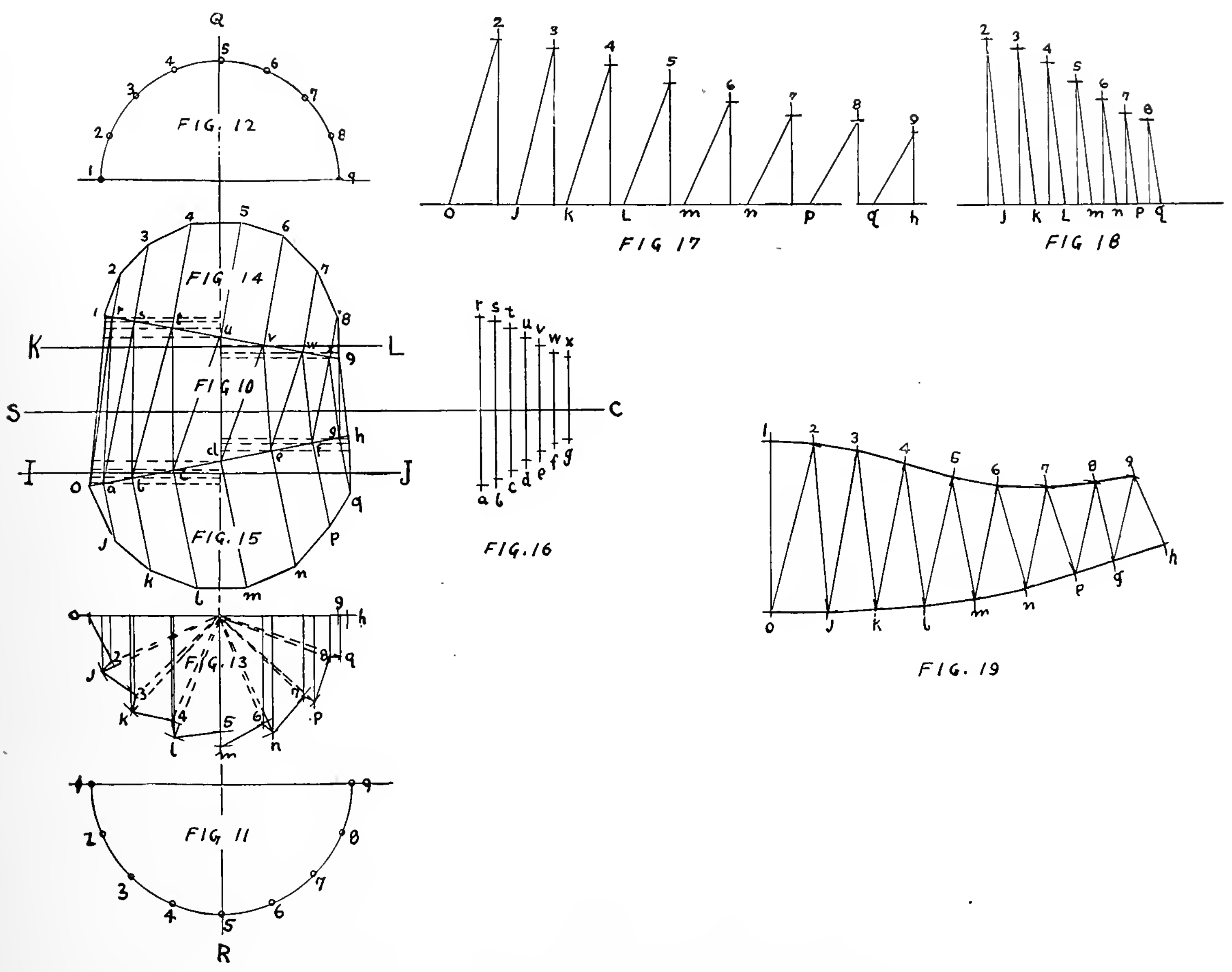
Now, in order to get a regular taper it is necessary to have the diameters of the ends of the different sections at the miter or joint lines. To determine these, set off on the line *AE* from *A*, the half diameter of the small end, which leaves the distance *JK* as the difference of half the diameters of the two ends. This difference must be divided into four equal parts, consisting of three whole and two half parts, just as the elbow is divided into three whole and two half sections, and the half parts should be at the end as shown. Then the distance *Aq'* is the half diameter on the joint line 7; the distance *Ap'* is the half diameter on the joint line 5; the distance *An'* is the half diameter on joint line 3, and *Am'* is the half diameter on the joint line 1.

Take these half diameters as radii, and from the intersections *q*, *p*, *n*, *m* as centers, strike arcs of circles at the back and in the throat; then by drawing straight lines tangent to these arcs, the back and throat are produced; then by connecting the vertical center line as a center and a radius *AE*, Fig. 1, strike a half circle 1, 5, 9 and divide it into eight equal parts and project the points 2, 3, 4, 5, 6, 7, 8 upward onto the horizontal line 1, 9, Fig. 2, locating the points 2-8, Fig. 2.

Above Fig. 2 erect Fig. 4, by drawing horizontal line 1, 9, and with a radius *Am'*, Fig. 1, strike a half circle and divide it into eight equal parts; then through Fig. 2, draw the horizontal line *FG* the same height from the base line 1, 9 as the point *m*, Fig. 1, is above *A*. Then project the points 1, 2, 3, etc., Fig. 4, down onto the line *FG*, Fig. 2. From the points 2, 3, 4, etc., on line 1, 9, Fig. 2, draw lines through the points on the line *FG*, cutting the miter line *Oh* and establishing the points *a*, *b*, *c*, *d*, etc. Then project these points down onto Fig. 3, making the vertical dotted lines; also from these points draw lines at right angles, as in Fig. 5; then through these points draw the horizontal dotted lines to the surface lines, having extended the line 9*h* up far enough so that the line drawn from *d* will intersect it.

Then with the compasses take the distance from the center

line to the surface line *1O,* which cuts through the point *a* and use it as a radius, and from the center of Fig. 3, cut the vertical dotted line in *a*. Again, take the distance from center to surface on dotted line, which cuts through the point *b,* and as before, using the center of Fig. 3, cut the vertical dotted line in *b*. Continue this until you reach the point *d,* Fig. 2. Then work from the other side, that is, from the center line out to and on these verticals, set off these different heights in succession as shown, marking each set with the corresponding letter at the top. Then, from Fig. 3, take the distance *2a,* and set it off on the horizontal line, Fig. 7, from the vertical *a,* establishing the point *2*; connect the points *2a*. This, you will notice, forms a triangle, of which *2a* is the hypotenuse. Then from Fig. 3, take the distance *3b* and set it off on the hori-



PATTERN FOR MIDDLE SECTION OF A 90-DEGREE TAPERING ELBOW.

the line *9h* and continue cutting the vertical dotted lines successively until all the points on Fig. 3 are established.

Then connect these points with the points on the base circle 1, 5, 9, Fig. 3, as *1a, a2, 2b, b3, 3c, c4,* etc., until all are connected. Take the distance from the line 1, 9 to *a,* Fig. 3, and set it off on the line *a,* Fig. 5, establishing the point *j;* then take the distance from the line 1, 9 to *b,* Fig. 3, and set it off on the line *b,* Fig. 5, establishing the point *k;* continue until all the distances are set off; then on the continuation of the line 1, 9, Fig. 2, erect a perpendicular, Fig. 9. Onto this perpendicular project the points *a, b, c, d, e, f, g* from Fig. 2. These points mark the vertical heights from the base line 1, 9 at the different points on the miter line *Oh*.

Now, we are ready to erect the triangles. Draw two horizontal lines as in Figs. 6 and 7. On these, draw vertical lines zontal line, Fig. 7, from the line *b;* connect the points *3b* and we have another triangle, of which *3b* is the hypotenuse. Continue this until you have taken all the distances from Fig. 3 and form triangles.

Then take the distance *a1,* Fig. 3, and set it off on the horizontal line, Fig. 6, from vertical *a* establishing the point 1: connect *1a* and another triangle is formed. Continue this process until all these distances are taken from Fig. 3 and the triangles in Fig. 6 are formed. Now, the object of this operation, and, in fact, all the operations gone through with in Figs. 2, 3, 4, 5, 6 and 7, is for the purpose of obtaining true distances. Since all the distances shown in Fig. 2, except *1O* and *9h,* and the distances 1, 2, 3, 4, 5, 6, 7, 8, 9, in Fig. 3, are in perspective you will see that the surface of the section Fig. 2, is cut up into triangles, and what we must do is to get the

distances or lines necessary to construct these triangles of their true size and lay them together in their proper places to form the pattern as shown in Fig. 8.

Now, let us lay out the pattern. Draw a vertical line as *1O*, Fig. 8; then take the distance *1O*, Fig. 2, and set it off on the vertical line, Fig. 8. Then take 1, 2, Fig. 3, and with 1, Fig. 8, as a center, describe the arc 2. Take the distance *O*; Fig. 5, and from *O*, Fig. 8, as a center describe the arc *a*. Then take the hypotenuse of the triangle *1a*, Fig. 6, and from the point 1, Fig. 8, as a center, strike an arc cutting the arc *a*. Take the hypotenuse *2a*, Fig. 7, and from the point *a*, Fig. 8, as a center, strike an arc cutting the arc 2. Now, if you will connect all these points with lines you will see that the two triangles have been formed, and laid down in correct relation to each other, forming the section of the envelope shown in Fig. 2 enclosed within the points *1O*, *a*, 2.

To continue, take the distance 2, 3, Fig. 3, and from the point 2, Fig. 8, strike an arc 3; then take the distance *jk*, Fig. 5, and from the point *a* strike an arc *b*; then take the hypotenuse *2b*, Fig. 6, and from the point 2, Fig. 8, as a center, strike an arc cutting the arc *b*; then take the hypotenuse *b3*, Fig. 7, and from *b* as a center, strike an arc cutting the arc 3. Continue this process until you have fixed the point *h*, Fig. 8; then with distance *9h*, Fig. 2, and with *h* as a center, strike an arc cutting arc 9, thus completing half of the pattern of the first section or large end. To this you will have to add the necessary laps.

Now proceed to lay out the next section. Draw a vertical line *QR*, running through all the figures from 11 to 12. Across this draw a horizontal line, as *CS*, Fig. 10, which represents the line *CS*, Fig. 1. On the line *QR*, from the line *CS*, step off the distances *m2* and *2n*, Fig. 1, and through these points draw the horizontal lines *IJ* and *KL*. Then on the vertical line *QR*, as in Fig. 11, describe a half circle, which is the same diameter as the circle struck from the center *m*, Fig. 1. Again, as in Fig. 12, describe another half circle the same diameter as that struck from center *n*, Fig. 1. Divide both these circles into eight equal parts, as you did in Fig. 3.

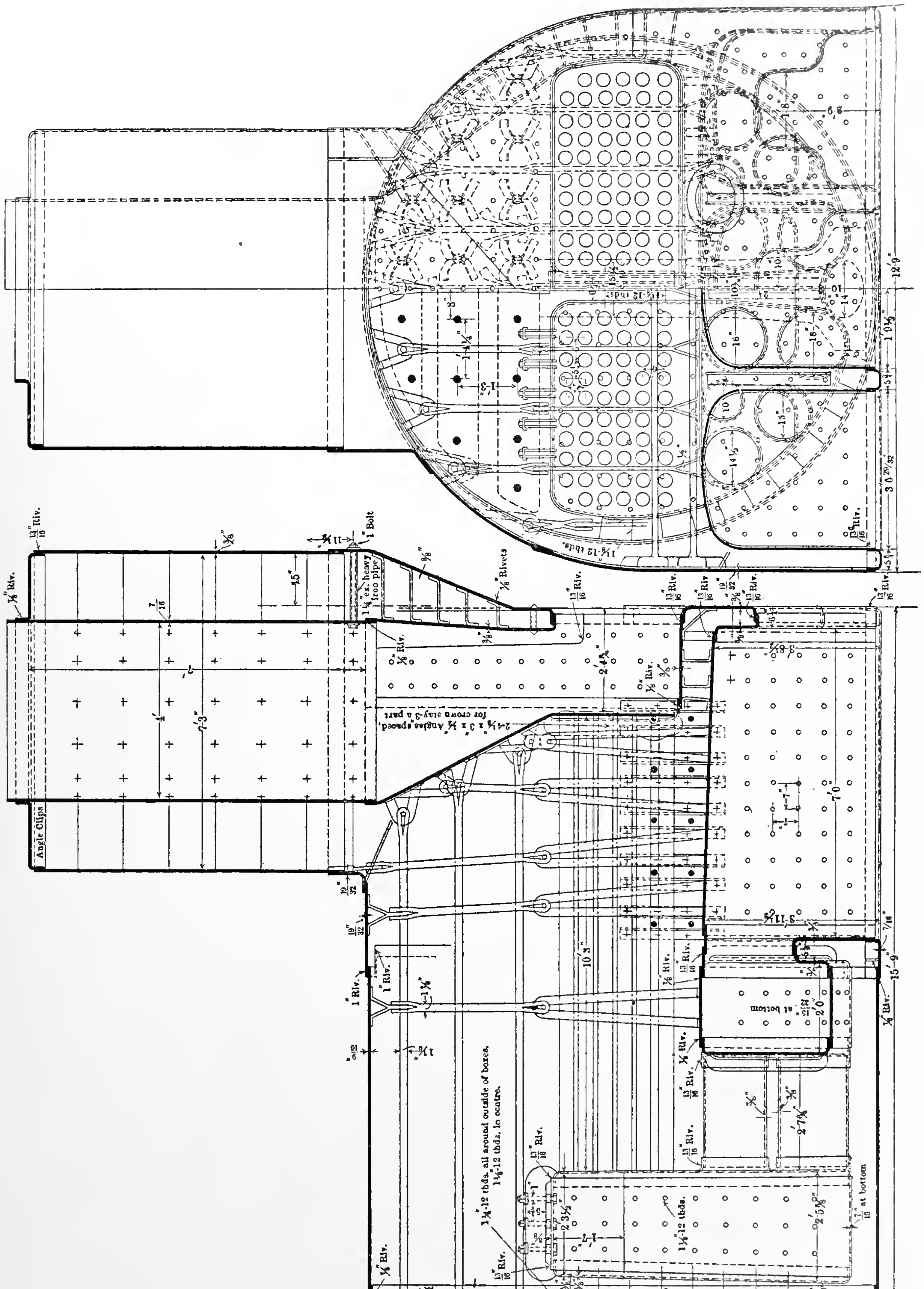
Project the points 1 to 9 on Fig. 11, upward onto the line *IJ*, and the points 1 to 9 on Fig. 12 down onto the line *KL*. Then draw the lines *O1* and *h9* by connecting the outside points on the lines *IJ* and *KL*, and on these slanting lines set off the following distances: From the line *CS*, Fig. 1, take the distance *SO*, Fig. 1, and set downward from the line *CS*, Fig. 10. Then take the distance *S1'*, Fig. 1, and set it upward from the line *CS*, Fig. 10. Take the distance *ch*, Fig. 1, and set it downward from *CS*, Fig. 10. Then take the distance *cP*, Fig. 1, and set it upward from *CS*, Fig. 10. Connect the points *Oh* and 1 9 with slanting lines, thus producing the miter or joint lines.

Now project the points from the lines *IJ* and *KL* downward and upward by connecting lines onto the lines 1 9 and *Oh*, establishing the points *a*, *b*, *c*, *b*, *c*, *f*, *g* on *Oh*, and *v*, *s*, *t*, *u*, *v*, *w*, *x* on the line 1 9. From these points draw lines at right angles to the lines 1 9 and *Oh*, on which to construct Figs. 14 and 15. Then as in Fig. 13, draw a horizontal line 1 9, project the points *a*, *b*, *c*, *d*, *c*, *f*, *g*, *h*, and at the same time draw the vertical lines from these points as shown. Again, on Fig. 10, draw the horizontal dotted lines through the points *a*, *b*, *c*, *d*, *c*, *f*, *g*, and *v*, *s*, *t*, *u*, *v*, *w*, *x*, to the surface lines *O1* and *h9*. Then with compasses take the length of the dotted line which runs through the point *a*, and with the intersection of the lines *QR* and 1 9 as a center, cut the line *a* in *j*. Again, take the length of the dotted line which runs through the point *b*, and from the same center cut the line *b* in *k*; continue this until you have got around to *g*.

Then take the length of the dotted line which runs through the point *r*, and from the same center, cut the line *v* in 2. Then take the length of the dotted line which runs through point *s* and from the same center cut the line *s* in 3. Continue this until you get around to *x*. Then connect these points with lines as follows: *O2*, *2j*, *3j*, *3k*, *k4*, *4t*, *t5*, *5m*, *m6*, *6n*, *n7*, *7p*, *p8*, *8q*, *q9*. These distances are the bases of the triangles in Figs. 17 and 18. Then transfer the lengths of the vertical lines on Fig. 13 to their corresponding lines on Figs. 14 and 15, as *r2*, *s3*, *t4*, on Fig. 14, and *aj*, *bk*, *cj*, etc., on Fig. 15. Connect the points 1, 2, 3, 4, 5, 6, 7, 8, 9, also *a*, *b*, *c*, *d*, *c*, *f*, *g*, *h*, with lines, and you have the profile of each end of the section. Next take out the vertical heights between the points *O1*, *ar*, *bs*, *ct*, *du*, *cv*, *fw*, *gx*, Fig. 10, by erecting on the line *CS* a perpendicular for each pair of points as shown in Fig. 16, and onto these project the points from Fig. 10.

Now we are again ready to form the triangles, Figs. 17 and 18. Draw two horizontal lines, and on these lines erect perpendiculars as shown, and on these set off the vertical heights taken from Fig. 16. Then take the distance *O2*, Fig. 13, and from the line 2, Fig. 17, set it off on the horizontal line. Take the distance *j3*, Fig. 13, and from the line 3, Fig. 17, set it off on the horizontal line. Do this with all the large bases on Fig. 13, and connect the points *O2*, *j3*, *k4*, and so on, thus forming all the large triangles. Then on the horizontal line, Fig. 18, set off the lengths of the short bases, *2j*, *3k*, *4b*, etc. Connect the points with the lines thus forming the other set of triangles, Fig. 18. Now we are ready to lay out the pattern, Fig. 19. Draw a vertical, *O1*. On this set off the distance *O1*, taken from Fig. 10. Then take the distance *Oj*, Fig. 15, and from *O*, Fig. 19, strike an arc *j*. Take the distance 1 2, Fig. 14, and from 1, Fig. 19, as a center, strike the arc 2.

Then take the hypotenuse *O2*, Fig. 17, and from *O*, Fig. 19, as a center, cut the arc 2; then take the hypotenuse and from 2, Fig. 19, as a center, cut the arc *j*, and connect the points so established with lines. Then take the distance 2, 3, Fig. 14, and from the point 2, Fig. 19, strike the arc 3; then take the distance *jk*, Fig. 15, and from the point *j*, Fig. 19, strike the arc *k*. Take the hypotenuse *j3*, Fig. 17, and from *j*, Fig. 19, cut the arc 3. Then take the hypotenuse *k3*, Fig. 16, and from the point 3, Fig. 19, cut the arc *k*. Connect these points with lines as before. Continue this process until you have established the point 9, Fig. 19, and described the arc *h*. Then take the distance *h9*, Fig. 10, and from the point 9, cut the arc *h*. Connect *h9* with a line, and half of the pattern of the section is completed, with the exception of adding the laps.



SECTIONS SHOWING THE DETAILS OF CONSTRUCTION OF A FLUE AND RETURN TUBULAR BOILER, 11 FEET 5 INCHES DIAMETER BY 15 FEET 9 INCHES LONG. STEAM PRESSURE 60 POUNDS PER SQUARE INCH.

A Flue and Return Tubular Marine Boiler.

The flue and return tubular type of marine boiler is little used to-day, having been superseded by Scotch and water tube boilers, which are much better able to carry the high pressures now used in marine work. In proportion to the space occupied, the flue and return tubular boiler has, however, a large grate area and for a low working pressure it is difficult to design a boiler which will be more efficient.

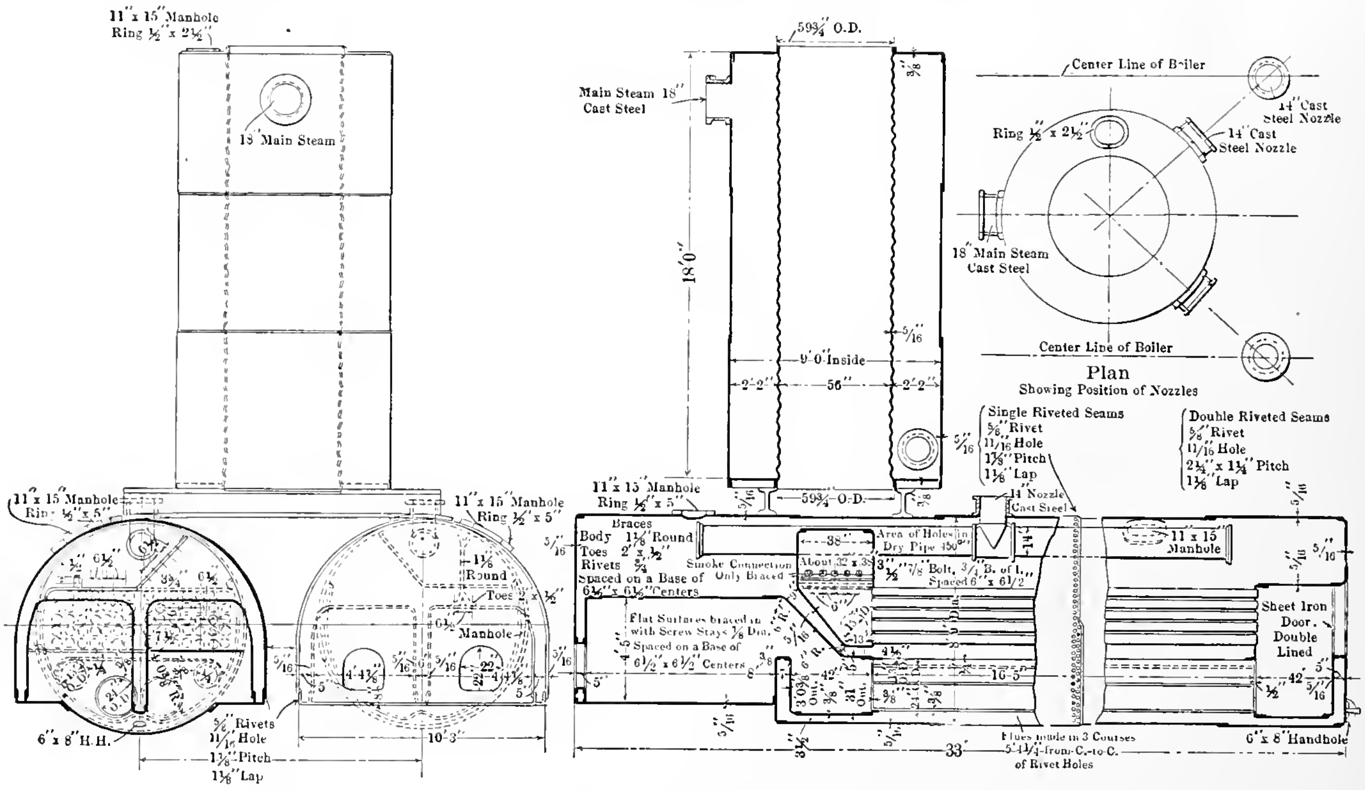
The furnaces, which are three in number, are surrounded by water legs 5¾ inches wide. At the rear of the furnaces is a combustion chamber from which ten large flues, ranging from 10 to 18 inches in diameter, lead to two large combustion chambers in the rear of the boiler. The return tubes, 130 in number, 4 inches in diameter, lead from the rear combustion chambers to the front tube sheet and smoke-box. The uptakes instead of being outside of the boiler, as in the Scotch marine type, lead up through a large steam dome or superheater 7 feet 3 inches in diameter by 7 feet high. The total grate area of the boiler is 73.5 square feet, and the total heating surface 2,205 square feet, giving a ratio of heating surface to grate area of 30. The working pressure is only 60 pounds per square inch.

The principal dimensions of the particular boiler illustrated are as follows:

Length of base	15 feet 9 inches.
Length over all, including steam chimney	17 feet.
Width of boiler front	12 feet 9 inches.
Diameter of boiler shell	11 feet 5 inches.
Height of boiler from bottom of leg to top of shell	11 feet 6 inches.
Height of steam chimney above shell of boiler	7 feet.
Diameter of steam chimney	7 feet 3 inches.

The plates in the boiler are worked as large as possible to avoid numerous riveted joints which would otherwise be necessary. The thickness of the cylindrical shell is 9-16 inch; of the front shell and side sheets 19/32 inch; of the furnaces and steam chimney shell ⅜ inch. Double riveting is used throughout the boiler, the rivets being ⅞ inch and 1 inch in diameter. All seams on the boiler are thoroughly calked both inside and outside. The 130 4-inch tubes are all number 10 B. W. G. seamless drawn tubes and are each tested to a hydrostatic pressure of 500 pounds per square inch.

This type of boiler, due to the low steam pressure carried, is very durable and reliable, its weakest feature being that, owing to poor circulation and inaccessibility for cleaning, the water legs are apt to deteriorate rapidly.



DETAILS OF LOBSTER BACK BOILER, SHOWING METHOD OF ARRANGING BATTERY.

A Lobster Back Boiler.

The lobster back boiler is a type which is little used except for marine purposes where only a low pressure is needed, as in the case of a slow-speed long-stroke beam engine. From its external appearance (see page 164), the boiler is apparently a plain tubular boiler with a modified form of locomotive firebox. Looking at the detailed drawings, however, it will be seen that its construction is much more complicated. The gases from the drop leg furnaces are led over a water leg arch to a small combustion chamber just beyond the furnaces and then through four large flues to a second combustion chamber in the rear of the boiler. From here they make a return pass through a number of small tubes to a third combustion chamber or smoke-box placed directly over the first one, whence the products of combustion are directed out of the boiler through an opening in the side. This opening is not seen in the photograph but is shown clearly in the detailed drawings. The exit of the gases from the boiler is made through the side, for the reason that two of the boilers are installed in a battery in connection with a common superheater.

The superheater consists of a vertical cylindrical shell containing an inner concentric corrugated flue through which the gases from the two boilers are led to the stack. In the particular boiler of which plans are shown herewith, the super-

heater is 9 feet in diameter by 18 feet in height, with an inner flue 56 inches in diameter. From the plan view it will be seen that steam pipes are connected directly from the dry pipes in each boiler to the lower part of the superheater, while the main steam outlet is placed at the top of the superheater.

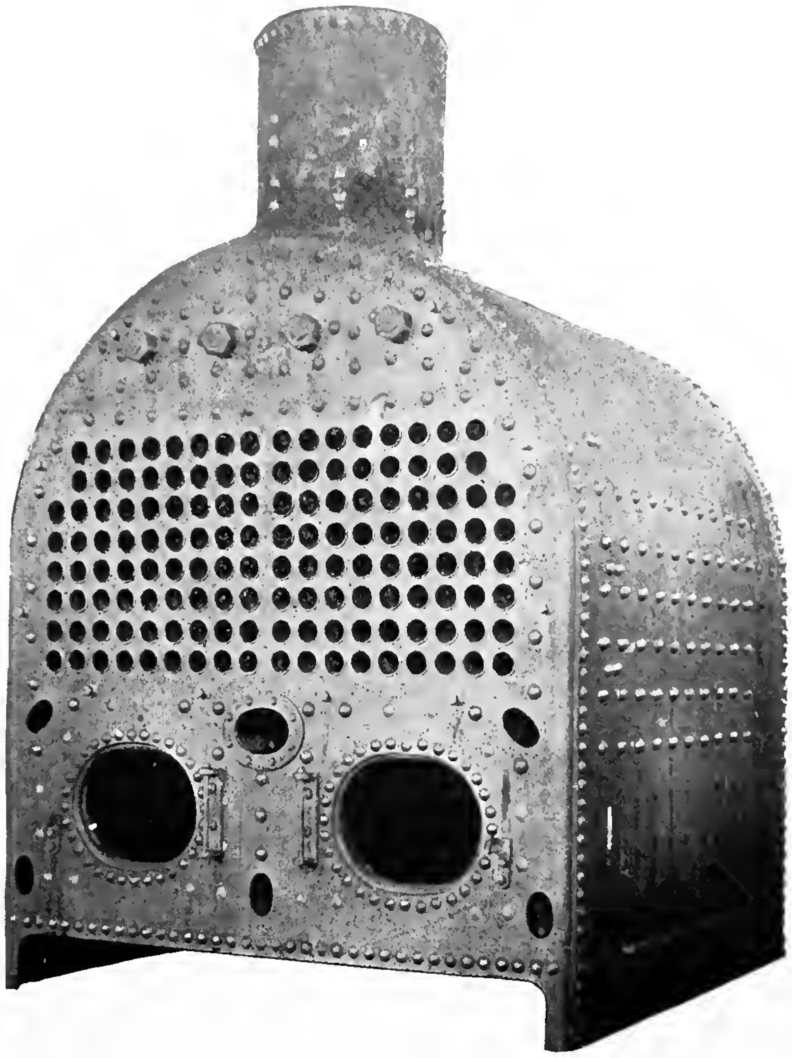
The details of the staying or bracing of this boiler combine the methods used in both a Scotch and locomotive boiler. All flat surfaces are stayed with screw stays 7/8 inch diameter, spaced 6½ by 6½ inches between centers. The through stay rods for the boiler heads are 1⅛ inches in diameter.

The shell and heads of the boiler are 5-16 inch thick, the shell being made in four courses. All girth seams are single riveted and all longitudinal seams double riveted lap joints. The steam pressure is only 55 pounds per square inch.

A Dog-House Boiler.

Replace the cylindrical shell and furnaces of a Scotch marine boiler by a shell and furnaces which have cylindrical tops and flat sides, and the resulting type of boiler is what is commonly known as a dog house boiler. The particular boiler of which a photograph and detailed drawings are shown on this page is 7 feet 6 inches long and 7 feet 6 inches high, with a steam dome 26 inches in diameter by 32 inches high. It is designed to carry 110 pounds steam pressure. There are two furnaces, each 26 inches wide and 70 inches long, made of 3/8 inch steel plate. The gases from both furnaces enter a common combustion chamber at the back of the boiler and from there are led back to the up-takes through 124 2½-inch tubes.

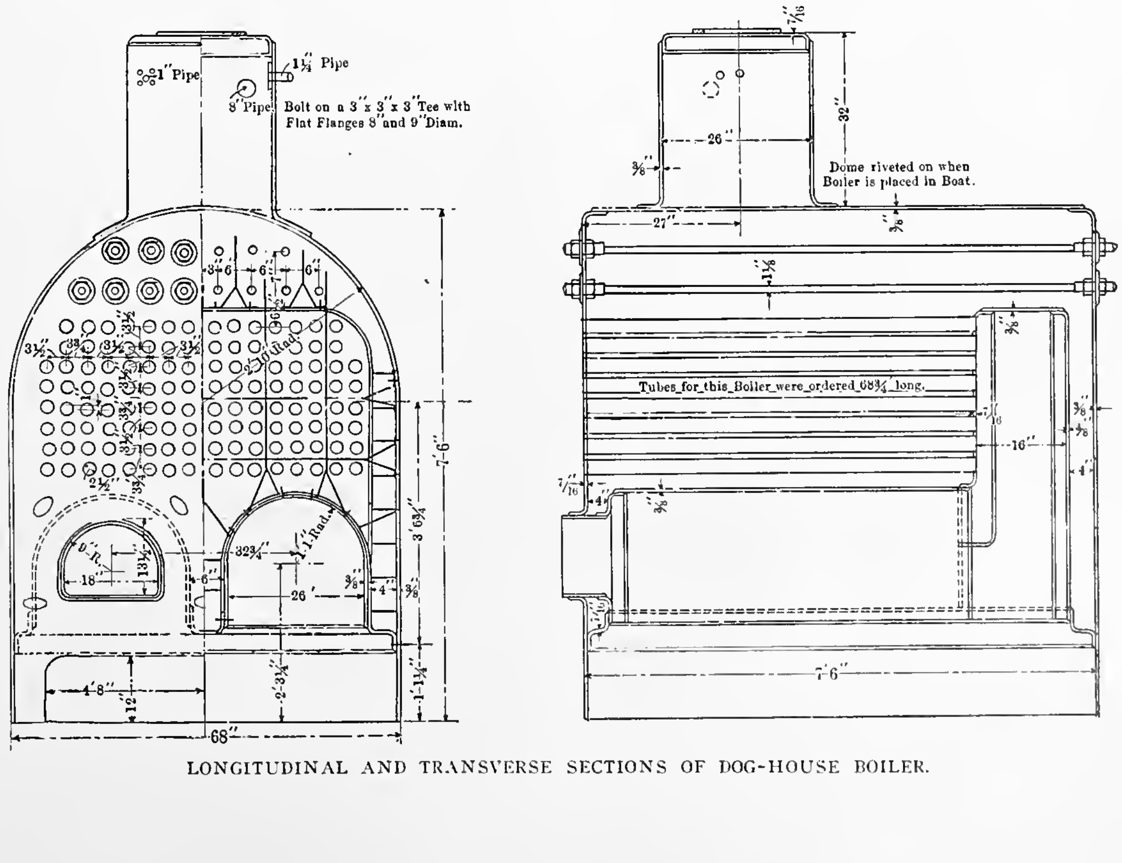
The lower edges of the furnaces and the combustion chamber are joined to the shell plate by a 7-16-inch S-shaped flanged plate, leaving a 4-inch water leg all around the lower part of the furnaces and combustion chamber. The flat plates throughout this water leg are stayed with ordinary screw staybolts. The tops of the furnaces and combustion chamber are stayed from the shell of the boiler by means of long sling stays attached to the plates with crowfeet. The segment of the boiler head above the tubes is braced by means of direct through stays, 1⅛ inches in diameter, pitched 6 inches between centers, the ends being secured by inside and outside nuts and washers in the same way as in an ordinary Scotch boiler.



A TWO-FURNACE DOG-HOUSE BOILER.

The shell of the boiler is made of 3/8-inch steel plate, with heads and steam dome of the same thickness.

This boiler presents no unusual features as a problem of laying out if the layout of a Scotch boiler is well understood.



LONGITUDINAL AND TRANSVERSE SECTIONS OF DOG-HOUSE BOILER.

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